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ADJUDICATION of the MEDALS of the ROYAL SOCIETY for the year 1876 by the PRESIDENT and COUNCIL.

The COPLEY MEDAL to Professor CLAUDE BERNARD, For. Mem. R.S., for his numerous contributions to the science of Physiology.

A ROYAL MEDAL to Mr. WILLIAM FROUDE, F.R.S., for his Researches, both theoretical and experimental, on the Behaviour of Ships, their oscillations, their resistance, and their propulsion.

A ROYAL MEDAL to Sir C. WYVILLE THOMSON, F.R.S., for his successful direction of the scientific investigations carried on by H.M.S. 'Challenger.'

The RUMFORD MEDAL to M. PIERRE JULES CÉSAR JANSSEN, For. Mem. R.S., for his numerous and important Researches on the Radiation and Absorption of Light, carried on chiefly by means of the Spectroscope.

The BAKERIAN LECTURE was delivered by Professor T. ANDREWS, LL.D., F.R.S.: it was entitled "On the Gaseous State of Matter."

The CROONIAN LECTURE was delivered by Mr. G. J. ROMANES: it was entitled "Preliminary Observations on the Locomotor System of Medusæ."

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XIII. *On Repulsion resulting from Radiation.*—Parts III. & IV.

By William Crookes, *F.R.S. &c.*

Part III. received January 5, Part IV. received February 5,—Read February 10, 1876.

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PART III.

125. In my previous papers on this subject* the experiments described have had for their object the demonstration of the broad facts of repulsion resulting from radiation. In Part I., after satisfying myself that the action was not due to air-currents or electricity, I went rapidly over bodies of the most diverse chemical and physical characters, organic and inorganic, metallic and non-metallic, dense and light, in spheres, disks, and thin plates, endeavouring to find, from their behaviour when free to move in a vacuum, what conditions were necessary to obtain the strongest movement under the influence of radiation, and what were unnecessary. I ascertained that chemical constitution had little or nothing to do with the action. I said (par. 75) "the law appears to be that the force exerted is in proportion to the extent of surface exposed, rather than in proportion to the mass. Much surface and extreme lightness are the requisites in selecting materials for the beam, index, or gravitating mass; and when the masses have the same specific gravity and extent of surface, their position in respect to the source of heat determines the extent of movement. Thus a cylinder of pith is more sensitive when arranged for the heat to act on its side than on its end." I tried many experiments on the circumstances governing the position of the neutral point during exhaustion, and I proved that, within experimental limits, the nearer the vacuum approached perfection the stronger was the movement due to radiation.

In Part II. I described many improved forms of apparatus by which the movements due to radiation could be studied in a more complete manner and numerical results be obtained; the action of the various kinds of radiation, from the obscure heat-rays emitted by copper at 100° C. to the blue and ultra-violet rays of the spectrum, was examined, the interference caused by passing the rays through various screens was shown, and the phenomena of the neutral point were further discussed. Experiments were described which satisfied me that the hypothesis of the movements being due to evaporation and condensation at the surface would not account for all the facts of the case; and ample proof was afforded that "to get the greatest delicacy in these apparatus there is required large surface with a minimum of weight," an apparatus for the quantitative examination of this law being described.

126. Nearly all the experiments described in Parts I. and II. were made with the

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* Philosophical Transactions, vol. clxiv. (for 1874) p. 501, and vol. clxv. (for 1875) p. 519.

dark or slightly luminous heat-rays—the fingers, a hot glass rod, hot copper, or a candle-flame being used as the source of radiation. I quote the following sentence from par. 94:—"Although I most frequently speak of repulsion by *heat*, and in illustrating any of the results obtained I generally use either the fingers or the flame of a spirit-lamp as a convenient source of radiation, it must be clearly understood that these results are not confined to the heating-rays of the spectrum, but that any ray, from the ultra-red to the ultra-violet, will produce repulsion in a vacuum. I have already mentioned this fact in my first paper (58, 68)."

A few experiments were tried on the effect of radiation on surfaces the reflecting or radiating power of which was modified by coating them with various substances. In par. 102, after describing a torsion-apparatus for quantitative work, I mention that the surfaces of pith, as thin as possible, may be coated with lampblack or silver, or may retain their natural surface; in par. 108 I state, as the result of a long series of experiments with this apparatus, that "the conducting-power for heat and condition of the surface (whether coated with lampblack or consisting of polished metal) of the body on which radiation falls materially influence the movements." In par. 112 I again refer to the effect caused by the physical condition of the surface; and further on, in par. 116, I say, "A series of experiments have been tried with a view to ascertain what influence the state of the surface of the substance submitted to radiation has on the amount or the direction of its movement." After describing one in which white ivory was compared with lampblacked ivory without giving very striking results, I continue:—"These experiments were, however, tried in 1873, when I had not succeeded in getting any thing like the delicacy I now obtain in the apparatus; and I propose to repeat them under varied conditions, before employing the results to found any arguments upon."

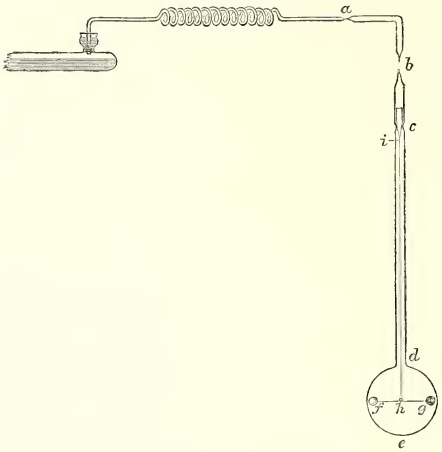
The present paper contains an account of these experiments on the action of radiation on bodies the surfaces of which have their radiating and absorbing powers modified by various coatings. The surfaces examined in this way are of the most diverse character, the incident rays have been selected of all refrangibilities from ultra-red to ultra-violet, the radiation has been sifted through liquid, solid, and gaseous screens, the degree of exhaustion and the sensitiveness of the apparatus have been brought to a state of perfection undreamed of in my earlier experiments, and the results, I venture to state, are of a correspondingly striking character.

127. The results which I obtained on comparing the action of radiation on thin substances, plain and lampblacked, were at first very anomalous. As already stated (116) the movement of lampblacked ivory under the influence of radiation was only a little more than that of plain white ivory. On the other hand, coating platinum with lampblack produced a very marked effect on its movement (114).

Pith coated with lampblack was generally found to have its sensitiveness heightened; but this was not always the case, and the following experiments were tried for the purpose of clearing up these discrepancies.

128. An instrument was made similar to the one described and figured in pars. 84, 85,

Fig. 1.



consisting of a glass bulb on the end of a tube, and having suspended in it, by means of a silk fibre, a horizontal glass stem with a disk of pith at each end. For a detailed description and the mode of exhaustion I refer to my last paper, the only point of difference being that in the present case one of the pith disks was coated with lampblack, the other remaining white.

Before exhausting the apparatus I found that the white and the black disk were attracted about equally by the fingers, a bulb of warm water, or a hot glass rod.

After exhausting it I tried the action again. The fingers repelled either disk strongly, and in about an equal degree; and the same result was obtained with other sources of heat of low intensity. If the finger, a bulb of warm water, or a warm piece of glass or metal is held for some time close to the glass bulb, the two disks are repelled, and the rod connecting them sets equatorially, showing that the repulsion is equal on the black and the white surface.

The bulb of water with enclosed thermometer (28) was raised to 100° C., and brought close to the bulb of the apparatus. The black and white disks were equally repelled, the connecting rod setting equatorially.

A bath of fusible metal was prepared. In this a small copper ball was heated to different temperatures, and the action on the black and white disks noted.

At 100° C. the repulsion of the two was equal.
150° ,, ,,
200° ,, ,,
250° ,, ,,
300° the black was slightly more repelled than the white disk, the rod setting about five degrees from the equatorial position.

The fusible metal bath was gradually increased in temperature up to dull redness, and the action of the copper ball heated in it was tested from time to time; the temperatures were not ascertained, as they were above the boiling-point of mercury. The repulsion of the black disk increased until at dull redness the copper ball caused the rod joining the two disks to make an angle of about 40 degrees. At a full red heat the ball repelled the black disk very strongly, causing the rod to oscillate violently, and sometimes even to pass the axial position.

129. A candle brought near the apparatus acted on the disks even more energetically than the red-hot copper. At a little distance off the movable rod set at an angle of 45 degrees; and by causing the candle to approach or recede, the angle formed by the rod varied in a corresponding manner, the torsion of the suspending fibre balancing the varying force of radiation.

130. During the exhaustion of one of these pieces of apparatus, an action of aqueous vapour was observed which explained some of the anomalies I had met with in the course of this investigation. The apparatus had a little water in it; and although the mercury-pump brought the gauge to within about 8 millims. of the barometric height in the course of ten minutes, the tension of the aqueous vapour prevented it from rising higher. After working the pump for several hours, and gently warming the different parts of the apparatus, the liquid water was evaporated, and only aqueous vapour remained. The gauge now rapidly rose to the height of the barometer, the apparatus necessarily being filled with the residual aqueous vapour. On bringing a lighted candle near the disks I expected to see the black one violently repelled; but instead of that the connecting-arm set equatorially, showing that the radiation from the candle within a few inches of the disks repelled the white one as strongly as it did the black. The pump was kept in action, and oil of vitriol was passed through it once or twice (44). This was continued for about four hours; and on testing the apparatus from time to time with a candle the repulsion of the black disk gradually increased, the arm setting at a greater and greater angle from the equatorial position, but at no time getting very strongly deflected.

An accident happening to one of the tubes of the pump, it was necessary to let air into the apparatus; it was passed in slowly over oil of vitriol. As soon as the pump was mended exhaustion of the apparatus was recommenced. As soon as the gauge rose within 6 millims. of the barometric height the candle was seen to repel the black disk. At 3 millims. the superior repulsion of the black over the white disk was sufficient to cause the arm to set 45°; and as the exhaustion got better the repulsion of the black disk increased, until at the point when the gauge and barometer were level the candle exerted a strong action many feet off, and when brought close to the instrument set the bar and disks in most violent agitation, the black disk being driven violently away, and the connecting-arm swinging rapidly on each side of the axial position.

This experiment shows that the presence of even a small quantity of aqueous vapour in the exhausted apparatus almost, if not quite, neutralizes the more energetic action which luminous rays appear to exert on a blackened surface. In the first case, even when the gauge and the barometer were appreciably level, and the pump had been working for some hours, the superior repulsion of the black over the white was not so strong as it was in the second case when the gauge was several millims. below the barometer.

131. These two experiments, the one showing a marked difference of action on a black surface between heat of low intensity and luminous rays, and the other showing that this difference may be neutralized by aqueous vapour, explain most of the anomalies I have met with; and especially they prove how it was that my earlier experiments with black and white surfaces failed to show much difference. They also prove that still further improvement in the vacuum-producing apparatus would be advisable. I accordingly adopted Dr. ANGUS SMITH'S and Professor DEWAR'S plan of absorbing the residual gas by means of cocoanut-shell charcoal; and I found that after a little experience this, although somewhat tedious, left little to be desired in the perfection of the vacuum. A glass tube about 6 inches long is tightly packed with small pieces of freshly ignited cocoanut-shell charcoal; it is then drawn narrow at each end and sealed on to the apparatus, between it and the spiral glass tube*. The exhaustion proceeds as usual till the gauge and barometer are appreciably level; the charcoal-tube is then heated to a temperature well within the softening point of the glass, when the occluded gases are given off from the charcoal and depress the mercurial gauge 30 or 40 millims. The pump is now worked rapidly until the gauge is brought up again; the heating of the charcoal is repeated, when more gas is given off and the gauge is again depressed, although not so much as before. The pump is again set going, and these operations are repeated until heating the charcoal ceases to depress the gauge. The effect of this has been to repeatedly wash out the residual atmospheric air and aqueous vapour from the interior of the apparatus, and replace it by gas or vapour which has been occluded by the charcoal, and which we are justified in supposing will be again occluded by it even when very highly exhausted. When these operations are finished, and no more gas is carried down by the mercury, the apparatus is removed from the pump by sealing off the tube at the narrow part between the charcoal and the spiral, so as to leave the charcoal still in connexion with the apparatus. The two together are now set aside for some weeks, when the charcoal will gradually absorb the whole of the residual gas and leave the vacuum so nearly perfect that it will not conduct an induction-current of electricity. In most of my experiments this refinement is not necessary; but in some, especially when working with the apparatus subsequently described, I prefer to adopt it. When it is considered that the charcoal has exerted its full action the tube containing it may be drawn off before the blowpipe, and the apparatus left ready for use.

132. The repulsion being due to the action of radiation on the surface of bodies, it became of interest to ascertain whether doubling the amount of incident radiation would produce double the movement. In my earlier apparatus I could not detect any

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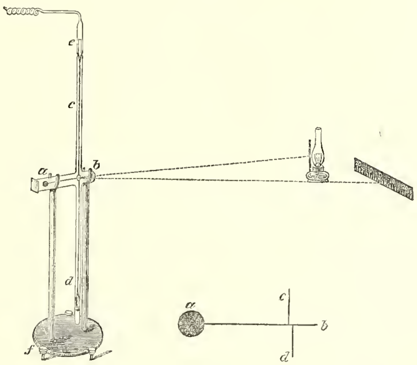
* In some of the subsequent woodcuts of apparatus (135, 145) this charcoal-tube is shown in its place.

such action as would show that it followed the law of inverse squares (109). There were, however, many reasons why this might not have come out with the apparatus then used; the glass torsion-thread might have been too stiff, or the source of light too near; the pith surfaces were white instead of black, and the vacuum was by no means so good as I have subsequently been able to obtain. The experiment described in par. 129, where the angle formed by the arm carrying the black and white disks was found to vary as the light approached or receded, appeared to me likely to afford valuable information on this point; and I accordingly fitted up more delicate apparatus on the same principle.

133. I wished to suspend the arm carrying the blackened pith in such a manner that it should move to the very slightest force, and still return accurately to zero when the force ceased to act on it. The principle of Professor Zöllner's horizontal pendulum[*] seemed well adapted for this; and I accordingly fitted up an apparatus shown in the annexed figure.

A tube (*a b*) about an inch in diameter has two narrower tubes (*c d*) blown on to it near one end, so that they shall be at right angles to the large tube, but not quite in the same straight line, the upper tube (*c*) being about a quarter of an inch nearer the end *a* of the wide tube. In the wide tube is a straw beam, carrying at the *a* end a disk of lampblacked pith, and at the other end a silvered glass mirror. At *e* is a plug of glass, firmly fixed in the tube *c*, and carrying a very fine glass thread. In the tube *d* is another similar thread of glass, having at the end a weight made of glass tube and mercury. The two threads are firmly fastened to the straw beam, behind the mirror, in such a manner that the upper thread in *c* holds the beam a quarter of an inch nearer the pith end than the lower thread in *d* holds it, as shown in the enlarged view. By adjusting the tension on the glass fibres, the beam can be kept in a horizontal position

Fig. 2.



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[*] Pogg. Ann. 1873, vol. cl. pp. 131, 134.

along the axis of the tube *a b*. The whole is supported on a stand furnished with finely cut levelling-screws, and, according to the principle of the horizontal pendulum, the sensitiveness of the beam to any force applied at the pith end can be increased or diminished at pleasure by tilting the end *a* of the apparatus up or down; this can be easily effected by turning the milled head of the screw *f*. A ray of light from a lamp is reflected from the mirror to a graduated scale, and appropriate screens are used to cut off from the pith disk all radiation, except that being experimented on. The apparatus is connected to the pump by means of the glass spiral shown at the upper part of the tube *c*. On lowering the end *a* of the horizontal tube, by means of the screw *f*, the oscillation of the beam becomes very rapid, and its sensitiveness diminishes. On raising the end *a* the time of oscillation can be increased to any desired amount, with corresponding increase in sensitiveness. The other levelling-screws are for the purpose of bringing the beam into the centre of the horizontal tube. If the tube is too much tilted up, the centre of gravity gets too high, and the pith falls to one side or the other of the tube. The most convenient degree of sensitiveness I found to be that accompanying an oscillation at the rate of one per minute.

The ray of light used as an index of movement was reflected to a graduated scale 4 feet off. The instrument, mounted and adjusted as above described and highly exhausted, was found to be very sensitive. A ray of light from a candle 10 feet off, falling on the pith, would cause the index ray to move through 15 divisions; when 5 feet off the index moved about 60 divisions, and when 20 feet off the index moved between 3 and 4 divisions. These movements were sufficient to show that the motion of the pith was in inverse proportion to the square of the distance the candle was from it.

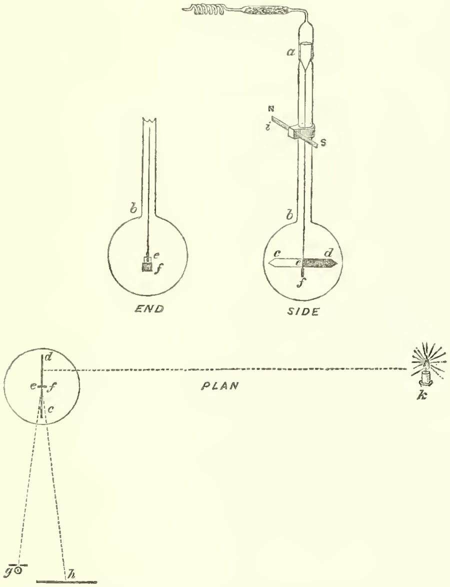
I tried numerous experiments with this apparatus, and verified the law perfectly; but there were difficulties connected with working with it which induced me to devise another instrument, free from the objections attending the use of the horizontal pendulum, and at the same time simpler to make and equally sensitive to faint radiation.

134. The objections to the use of the horizontal pendulum were the following:—When sufficiently sensitive to indicate readily the action of faint light, I found it almost impossible to bring the index to zero; the oscillations were so slow, and, taking place in a vacuum, kept on for so many minutes that my patience became exhausted with waiting for the next observation. But if I ventured to move away, or, when standing close to the apparatus, even to shift the weight of the body from one leg to the other, that was sufficient to alter the level of the floor, and therefore of the horizontal beam; the spot of light would suddenly fly ten or twelve degrees in another direction, and all the tedious waiting had to be gone over again, and possibly another zero had to be taken. A person running up stairs, a child playing in the adjoining room, a passing carriage, or a railway-train, all had their influence on the level of the laboratory floor. I tried fixing the apparatus to a main wall of the house, but this did little good. When the instrument was brought to its highest pitch of sensitiveness, to watch the move-

ments of the index ray when it should have pointed to zero gave one the impression that my house rested on an india-rubber cushion, so sensitively did it shift its level in obedience to a passing vehicle; and yet it is very well built, and the part where my work is mostly done was erected by myself some years ago, and was made of extra strength for the purpose of physical research. An incredibly small angular movement of the base of the instrument is, however, sufficient to cause the luminous index to move. In a paper by Professor O. N. Rood*, "On the application of the Horizontal Pendulum to the measurement of minute changes in the dimensions of Solid Bodies," the author illustrates his method of determining the change of volume of bodies. The levelling-screw of his instrument, corresponding to screw *f* in my apparatus (fig. 2), rests on the body the change in whose dimensions is the subject of study (such as a bar of iron about to undergo magnetization). Professor Rood gives experiments which show that an increase of thickness under the screw equal to the $\frac{1}{36,204,000}$ of an inch is an appreciable quantity!

135. The following apparatus (fig. 3) is much simpler than the horizontal pendulum,

Fig. 3.



and is free from the objections noted above; whilst its available sensitiveness is almost as great, and has the advantage of being capable of being increased or diminished within very wide limits.

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* Read before the National Academy of Sciences, November 4th, 1874, and published in 'Silliman's Journal' for June 1875.

A glass tube (*a b*), 16 inches long and 1 inch diameter, has a 4-inch bulb blown on to the lower end. *c d* is a bar of pith $\frac{3}{4}$ inch wide, $3\frac{1}{4}$ inches long, and $\frac{1}{16}$ inch thick. One half (*d*) is coated with lampblack, and the other half left white, as shown in the figure. The pith bar is suspended in the bulb by a very fine cocoon fibre. Through the centre of the pith bar, at *e*, and at right angles to it, is passed a magnet (101) about $\frac{1}{4}$ inch long, made out of a fine steel sewing-needle. To the ends of this magnet are attached cocoon fibres, which support a small square of silvered glass (*f*), hanging freely below the pith bar and at right angles to it; a reference to the *end* view will show the arrangement. At the upper part of the tube (*a b*) are seen the tube filled with cocoanut-shell charcoal, and the spiral glass tube for connexion with the mercury-pump. The arrangement for an experiment is shown in fig. 3, *plan*. A ray of light (*g f h*) from a slit in front of a lamp falls on the mirror (*f*), and is thence reflected on to the scale (*h*). The apparatus is so placed that the index ray falls near zero when the magnet (*e*) has assumed its normal north-south position. It may be brought accurately to zero, and the sensitiveness increased or diminished at will, even during an experiment, by means of a control-magnet on a cork sliding up and down the tube, as shown at *i*, either close to the bulb or at some distance off, and acting with or contrary to the earth's magnetism, according to the sensitiveness required.

The instrument was exhausted and reexhausted, with repeated heatings of the charcoal-tube, in the manner already described (131). It was finally sealed off from the pump, the charcoal still remaining attached to it, and it was set aside for some months. The following experiments were tried with it after it had arrived at its maximum sensitiveness:—

136. The bulb was placed in a box lined with black velvet, apertures being cut to allow the index ray to pass in and out and the experimental light to fall on it. The index ray was passed through diaphragms in cards and a cell of water, to keep the heat from the lamp from acting on the pith. The face of the pith was also protected by black screens from all side radiation, and the path of the experimental ray of light was guarded on each side by a double row of bottles filled with water, and packed at the top and bottom with cotton-wool. Without this precaution I was unable to go sufficiently near the apparatus to observe the movement, without introducing irregularities from the heat of my body. The light was only allowed to shine on the black surface of the pith, a screen shading it from the white half.

The scale (*h*) on which the index ray of light (*g f h*) fell was 5 feet 6 inches from the hanging mirror (*f*). It was divided into millimetres; the measurements given below are the actual movements of the index ray of light along this millimetre-scale. The candle (*k*) was a "parliamentary standard" (109). It was surrounded on three sides with black velvet screens, and an assistant, standing close to it, raised or depressed a black shade in front of it, as I called "light" or "dark," watching the index ray of light at the same time.

No one moved during the experiment, and the room was in perfect darkness (except from the candle) and was of a uniform temperature.

Each recorded observation is the mean of three or four. I did not carry the series beyond 35 feet, as that was the greatest distance I could get in my laboratory.

Distance between standard candle and pith bar of instrument.	Movement of luminous index on millimetre-scale, 5 feet 6 inches from the hanging mirror, in millimetres.	
	With no screen interposed.	With a glass screen, 2 millims. thick, interposed.
feet.	millims.	millims.
35	9·0	6·0
34	13·0	8·0
33	14·0	9·5
32	11·5	7·5
31	13·5	9·0
30	13·5	8·5
29	16·0	10·5
28	14·0	9·0
27	16·5	11·0
26	23·5	15·5
25	18·0	11·5
24	19·5	13·0
23	23·5	15·5
22	23·5	15·0
21	26·0	17·5
20	28·5	19·0
19·5	31·0	20·5
19	32·5	21·5
18·5	33·0	22·0
18	37·5	24·5
17·5	39·5	26·5
17	43·0	28·5
16·5	43·5	28·5
16	45·5	30·5
15·5	50·5	34·0
15	52·5	35·0
14·5	56·0	37·5
14	63·5	42·5
13·5	66·0	44·5
13	71·0	47·5
12·5	78·0	51·5
12	82·5	54·0
11·5	87·5	58·5
11	96·5	64·0
10·5	108·5	72·0
10	114·5	77·0
9·5	133·0	89·5
9	147·0	97·5
8·5	165·0	111·5
8	190·0	125·0
7·5	210·0	138·0
7	244·0	162·5
6·5	279·5	187·0
6	325·0	218·0

I could not take measurements with the candle nearer than 6 feet, as the index went off the scale. The diagram fig. 4, Plate 35, shows graphically the above series. The isolated dots show the experimental observations, whilst the continuous lines show the curves which the observations ought to have taken according to the law of inverse squares. The agreement is sufficiently close to prove that the force of radiation varies inversely with the square of the distance of the source. The discrepancies, especially at the greater distances, are considerable. Some are doubtless due to irregular torsion of the silk fibre, to interfering heat which penetrated the screens, to some of the observations following too closely those preceding them, but chiefly to the irregular burning of the standard candle. Indeed this cause alone is sufficient to account for all the discrepancies between theory and experiment; and it would appear to be very active in some cases, as a reference to the diagram will show. The observations with the glass plate in front followed immediately after the corresponding observation with the naked flame, so that if the candle were burning irregularly in one instance it would probably be burning irregularly in the other. The diagram shows the observations to agree pretty well with theory from 6 feet off to 9·5 feet. At 10 feet the action of the naked flame is less than it ought to be, and this is repeated when the sheet of glass is interposed. At 14 feet off the naked-flame observation shows more action than is required by theory, and the observation behind the glass plate is also in excess. The dots at 16, 17, 18·5, 22, 24, and 25 feet follow the same rule; where one is in excess or deficient the corresponding one repeats the error. At 26 feet off the candle must have been burning with extra brilliancy, for the action on the pith is as strong as it was when the candle was only 23 feet off; and almost identically the same thing is noticed when the plate of glass is interposed and the corresponding observation taken; at 33 and 34 feet off the same discrepancies occur. Altogether I consider that the comparison of these curves shows that unequal burning of the candle must be credited with most of the discrepancies.

137. This apparatus was now placed so that I could put a candle or other source of light on each side of it; and its sensitiveness was greatly diminished by lowering the controlling magnet. A thin glass screen was placed on each side of the black velvet box containing the bar-apparatus. The scale, divided into millimetres, was placed 5 feet 6 inches from the bar. No screen was put in front of the white half of the pith bar, the movement, under the influence of radiation, being a differential one, due to the superior sensitiveness of the black over the white surface:—

1 candle,	48	inches from bar, deflected the luminous index	. 90	millims.
2 candles,	48	,, ,, ,, ,,	. 177	,,
2 ,,	72	,, ,, ,, ,,	. 98	,,
1 candle,	72	,, ,, ,, ,,	. 50	,,
1 ,,	36	,, ,, ,, ,,	. 180	,,
3 candles,	72	,, ,, ,, ,,	. 160	,,

These results are sufficiently close to theory for the differences to be accounted for by variations in the light of the candle used.

138. A candle was placed 36 inches from the bar, and the deflections of the index were taken, after various screens were interposed in the path of the light (109):—

Candle, naked flame	180	millims.
Do. shining through yellow glass	161	,,
Do. ,, ,, blue glass	102	,,
Do. ,, ,, green glass	101	,,
Do. ,, ,, red glass	128	,,
Do. ,, ,, $40\frac{1}{2}$ millims. greenish glass	125	,,
Do. ,, ,, 81 ,, ,,	99	,,
Do. ,, ,, $3\frac{1}{2}$ millims. of water in cell	48	,,
Do. ,, ,, $7\frac{1}{2}$,, ,,	47	,,
Do. ,, ,, alum plate 5 millims. thick	27	,,

139. A candle was now placed on the left side of the bar, 48 inches off. The luminous index moved 95 millimetres. Another candle was placed on the right side of the bar, 48 inches off. It drove the index back to zero, and, after a few oscillations, kept it stationary a few millimetres the other side of it. I moved the right-hand candle 49 inches off, and the index soon stood steadily at zero. By shading off either of the candles the index ray instantly moved 95 millimetres one side or the other. This gives a ready means of balancing two sources of light one against the other. Thus, retaining the standard candle 48 inches off on the left of the bar (deflection of index=95 millims.), the index was brought to zero by

2 candles, on the right	67	inches off.
1 candle, behind solution of sulphate of copper $7\frac{1}{2}$ millims. thick	6	,,
1 ,, ,, alum plate 5 millims. thick	14	,,
A small gas-flame (bat's-wing)	113	,,

140. These experiments show how conveniently and accurately this instrument can be used as a photometer. By balancing a standard candle on one side against any source of light on the other the value of the latter, in terms of a candle, is readily shown; thus, in the last experiment, the standard candle 48 inches off was balanced by a small gas-flame 113 inches off. The lights were therefore in the proportion of 48^2 to 113^2; or as 2304 : 12,769, or as 1 : 5·5. The gas-burner was therefore equal to $5\frac{1}{2}$ candles.

By interposing screens of water or plates of alum, and so cutting off all the dark heat, the actual luminosity is measured. In addition to this, by interposing coloured glasses or solutions, any desired colours can be measured, either against the total radiation from a candle, its luminous rays, or any desired colour. One coloured ray can be balanced against another coloured ray by having differently coloured screens on either side. If one screen is a cell of iodine in disulphide of carbon, dark heat can be balanced on one side against light and colour on the other side (109, 110).

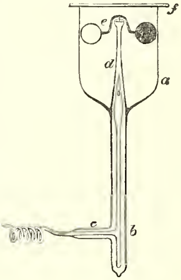
Again, the variations in the luminosity of a "standard" candle will cease to be of importance. Any candle may be taken, and if it be placed at such a distance from the bar as to give a uniform deflection (say 100 millims.), the standard can be reproduced at any subsequent time; and the burning of the candle may be tested during the photometric experiments by taking the deflection it causes from time to time, and altering its distance, if needed, to keep the index at 100 millims.

141. When a strong light is brought near this apparatus the bar receives an impulse which, unless the magnetic control is very strong, spins it round and round several times. If two strong lights are presented to it on opposite sides the bar oscillates rapidly from one to the other. As the lights are withdrawn to a greater distance the oscillations get smaller, until the bar settles down to a fixed position, dependent on the relative intensities of the lights shining on it.

142. Another instrument was constructed like the one last described (135), but the pith bar was blacked on alternate halves, instead of having the same half blacked on each side. By this construction an impetus given to the bar by a beam of radiation would always act in the same direction of movement, the right half of the pith surface presented to the light being always black, and the left half of the pith always white, so that, if the impulse were strong enough to carry the bar beyond the dead centre, continual rotation would be produced. Experiment fully confirmed this supposition. When even imperfectly exhausted, the suspended bar rotated when a candle was brought near it; and after more complete exhaustion it spun round rapidly, under the influence of radiation, so that the suspending fibre was twisted up, and ultimately stopped the movement by the accumulated torsion.

143. Were the black and white surfaces mounted on a pivot, like a compass-needle, instead of being suspended on a silk fibre, the movement would not be stopped by torsion. The friction, however, would possibly interfere. To test this an apparatus was fitted up, as shown in fig. 5. *a* is a glass vessel open at the top, and attached to a hollow glass stem (*b*), which is sealed up at the lower end. At the side of *b* a tube (*c*) is attached, which is connected by the glass spiral to the mercury-pump. To the hollow stem a piece of glass tube (*d*) is cemented by fusion so as to remain fixed in the position shown. The upper part of *d* is drawn somewhat narrow before the blowpipe, and in it is cemented a small cup-shaped ruby. The top of the vessel *a* is ground quite flat, and a ground-glass cover (*f*) can be cemented on (83). The movable part of the apparatus is shown at *e*; it consists of a fine curved brass wire with a needle-point soldered to the centre, and having a very thin disk of pith, half an inch in diameter, cemented on to each end. Each disk of pith is lampblacked on one side and plain white on the other, and they are fastened on so that one black and one white surface is always visible. The movable arms are balanced so that they turn easily to the slightest

Fig. 5.



impulse when the needle rests in the cup. The apparatus being arranged as shown, the cap is cemented on and the whole is exhausted.

144. When the vacuum is within a few millimetres of being perfect, the arms of this instrument move when a candle is brought near; as the pump continues working rotation commences, which gets more and more rapid, until, with the candle close to the glass, several revolutions are made per second. When well exhausted, the following experiments were tried:—

A flask of boiling water, placed 1 inch from the outer glass, caused the arms to set at right angles to the line joining the flask and the pivot, showing that the heat from boiling water acts on black and white surfaces equally (128).

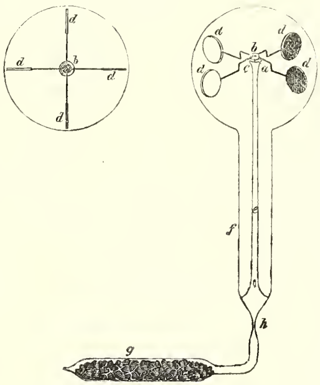
Copper at 400° C. kept the arms revolving, at first quickly, then slowly, until, as the copper cooled, the rotation stopped, and the black and white surfaces ultimately set equidistant from the hot metal (128).

A candle always set the arms revolving, when it was near enough for the force to overcome the friction.

This showed that rotation was possible, and that it would be kept up as long as the radiation lasted; and I accordingly devised a form of apparatus which would enable this action to be shown with greater facility. Owing to there being only two disks, the action of light was not uniform, as if it struck the arms at the end, instead of at the side, movement would not be commenced. Also the cement joint rendered it impossible to get the vacuum very good, whilst it took away from the permanent character of the instrument. After many trials of different arrangements, an instrument was made which had none of these defects, whilst it showed the movement of rotation in a very convenient manner.

145. The apparatus is shown in fig. 6. It consists of four arms, of very fine glass, passing horizontally through pieces of pith (*b*), and afterwards bent twice at right angles, as shown in the figure. Through the centre of the pieces of pith (*b*) is passed vertically the point of a very fine sewing-needle (*a*), which rests in a glass cup (*c*) blown on to the end of the glass tube *e*. At the end of each glass arm is fastened a thin disk of pith, white on one side and lampblacked on the other, the black surfaces of all the disks facing the same way. The whole is enclosed in a glass bulb blown on to the end of a wide tube. *f* is a piece of cement to keep the support (*e*) in its place. *g* is the tube containing cocoanut-shell charcoal; the other end is sealed on to the mercury-pump. The exhaustion is effected as already described (131); and the apparatus is then sealed off, with the char-

Fig. 6.



coal-tube still attached to it. Ultimately, when all the residual gas has been absorbed by the charcoal, a flame is applied to the contracted part of the tube at *h*, and the charcoal-tube is disconnected.

146. Before adopting the above method of making these instruments many experiments were tried, both to secure ease of manipulation and greater delicacy of action. The cup supporting the needle-point was made of ruby, sapphire, chrysolite, aquamarine, and agate; it was, however, found that these offered no advantage over glass, as the friction was not sufficient to produce any abrasion of the glass by the steel point. The disks at the end of the arms were made of every imaginable substance which was likely to answer. Among these I may mention wood, paper, flies' and butterflies' wings, talc, mica, selenite, thin glass, metals of various kinds, ivory, cork, and pith (86). For general purposes I prefer pith, as it is easily cut into slices, is extremely light, dries readily in a vacuum, and does not evolve vapour subsequently; besides which its natural white surface is almost as insensitive to radiation as any substance I have yet examined.

The number of disks has been varied from ten, the maximum which can follow one another without available surface being uselessly obscured, to two, or even one, which latter form has been experimented with, and possesses some advantages. Six disks are a useful number; but as the difficulty of making these instruments increases with the number of arms and disks to be got into the bulb, I prefer four disks for ordinary purposes.

The material of which the arms are made has also been the subject of experiment. My earlier instruments (exhibited at the Soirée of the Royal Society on the 7th of April, 1875) had straw arms. These are, however, too heavy, and are liable to evolve vapour after being kept in the vacuum for some time. An inorganic body is preferable; and I have finally adopted either thin rolled brass or fine glass thread drawn from thermometer tubing.

The colour of the disks has also been experimented on. During this part of the inquiry many curious results have been obtained, which will be described further on. At present, however, I have found nothing better than lampblack for the black surface and the freshly cut pith for the white surface. In working with cork, metals, &c., where the natural surface is not white enough, oxide of zinc may be used as a coating for the white surface.

147. The lampblack is best applied to the pith surface in the following way:—Camphor is burnt, and a sheet of glass is held close over the flame. An abundant deposit of lampblack takes place. A brush dipped in alcohol is then rubbed over the deposit, and the surface is painted over with the mixture. The lampblack adheres very well to pith, and in a few hours the alcohol and moisture have dried off, and a dead black, very even surface is the result. In some cases I smoke this again over burning camphor; but this is not of much use, unless the first coating shows glistening patches or is not laid on evenly.

148. I have proposed for this instrument the name of the *Radiometer*, as it serves to

measure the amount of radiation falling upon it by the velocity with which it revolves. It may also be called the *Light-Mill.* The rapidity of revolution is directly proportional to the intensity of the incident rays. Several radiometers, of various constructions, were exhibited at the Soirée of the Royal Society on April 7th, 1875. The following experiments have been tried with radiometers of different kinds and very varying sensitiveness. I could easily have obtained better curves and closer accordance with theory by repeating some of the observations with more recent instruments; but the results already obtained are sufficient to prove the laws, and I could do no more than this were I to repeat the experiments.

As soon as the radiometer was seen to revolve it was apparent that the stronger the light the more rapid was the movement. The second instrument which was made, the vacuum being very imperfect, the moving parts (straw arms and pith surfaces) heavy, and the instrument accordingly comparatively insensitive, was mounted for the purpose of testing its action at different distances.

The radiometer was covered with a thin glass shade, and in front of this was a large sheet of plate glass. The whole was covered on three sides and the top and bottom with black velvet, the fourth side admitting the light from the lamp. The source of light was one of DIETZ's paragon lamps, burning paraffin-oil. This lamp I find gives the brightest light and steadiest flame of any I have tried. Black velvet screens were put round the lamp, except on the side facing the radiometer. The room was darkened, and the temperature was kept uniform. The radiometer was kept fixed, and the lamp was moved backwards and forwards along a graduated scale, the number of seconds required for the radiometer to make one revolution being recorded by a chronograph watch. The following Table gives the results:—

Distance between Radiometer and centre of lamp-flame, in millimetres.	Number of seconds of time required for the revolution of the Radiometer.
150 millims.	6 seconds.
200 ,,	8, 9 ,,
250 ,,	11 ,,
300 ,,	15, 16 ,,
350 ,,	20 ,,
375 ,,	21 ,,
400 ,,	23, 24 ,,
450 ,,	29, 31 ,,
500 ,,	34, 36 ,,
550 ,,	40, 42, 44 ,,
600 ,,	52 ,,
650 ,,	60 ,,
700 ,,	65 ,,
750 ,,	74 ,,
800 ,,	82, 84 ,,
850 ,,	93, 95 ,,
900 ,,	100, 102 ,,
950 ,,	116 ,,
1000 ,,	129 ,,
1050 ,,	140 ,,
1100 ,,	158 ,,
1150 ,,	170 ,,
1200 ,,	184, 188 ,,

The diagram Plate 36. fig. 7 shows the curve formed by these observations. The isolated dots show the experimental observations, and the continuous line gives the theoretical curve which ought to have been followed according to the law of inverse squares. They are sufficiently concordant to show that this is the law governing the movements of the radiometer. The diagram illustrating this was laid before the Royal Society on April 22, 1875; I therefore prefer to retain it rather than prepare another one with a more sensitive instrument.

149. I next wished to ascertain if the speed of rotation would increase directly with the number of candles, the same distance off, shining on the instrument.

The same radiometer that was used in the last experiment was placed in the centre of a circle, 2 feet diameter, having 24 standard candles arranged symmetrically round the circumference. All the candles were lighted at first, and the times of revolution taken as they were removed one by one.

Number of candles burning 1 foot off.	Number of seconds required for one revolution of Radiometer.
24	6·4 mean.
23	7 ,,
22	7·5 ,,
21	8·5 ,,
20	9·5 ,,
19	10 ,,
18	11 ,,
17	11·3 ,,
16	12 ,,
15	13 ,,
14	13·3 ,,
13	14·5 ,,
12	16 ,,
11	17 ,,
10	18·5 ,,
9	19·7 ,,
8	21 ,,
7	23·5 ,,
6	28 ,,
5	35·5 ,,
4	44·5 ,,
3	59 ,,
2	92 ,,
1	180 ,,

The diagram shown in Plate 36. fig. 8 gives these observations, with the theoretical curve. Like the last one, this diagram was handed in to the Royal Society on April 22nd, 1875.

With a recently made instrument I should have been able to obtain better results. A radiometer now before me will revolve once in eight seconds to the light of a candle 1 foot off, whilst 24 candles make it spin with such velocity as to become almost invisible.

150. From the construction of the radiometer it is evident that the position of the light in the horizontal plane is of no consequence, provided the distance is not altered. This was tested during the last-described experiment. When a candle had to be removed, it was found to make no difference from what part of the circle it was taken. The following experiments were tried to further verify this result, the radiometer being a different one from that last used:—

	seconds.
1 candle, placed 1 foot from centre of radiometer, gave 1 revolution in 78 seconds (78×1=)	78
2 candles, placed 1 foot from centre of radiometer and put close together, gave 1 revolution in 39·5 seconds (39·5×2=)	79
2 candles, placed opposite to each other, gave 1 revolution in 39 seconds (39×2=)	78
3 candles, close together, gave 1 revolution in 26·5 seconds (26·5×3=)	79·5
3 candles, spread round circumference, gave 1 revolution in 26 seconds (26×3=)	78
4 candles, close together, gave 1 revolution in 19 seconds (19×4=)	76
5 candles, close together, gave 1 revolution in 16 seconds (16×5=)	80
5 candles, spread round circumference, gave 1 revolution in 15·5 seconds (15·5×5=)	77·5

151. I wished now to ascertain what would be the effect of bringing a radiometer into a uniformly lighted space, so that there should be no difference of action on any side.

A radiometer was covered over the top with a large sheet of paper, and the light from an argand gas-burner was reflected vertically downwards on to the paper. The apparatus was arranged so that, as near as possible, exactly the same amount of light should illuminate the instrument all round. The arms revolved at a uniform speed of one revolution in six seconds, and kept on at this rate as long as the experiment lasted.

A radiometer was taken on to the roof of the house, where there was an almost uninterrupted view all round. The sky was of a uniform dull leaden colour, a cold north-east wind was blowing, and, as far as the eye could judge, there was no difference in the amount of light received from any quarter of the sky. The radiometer was covered with a white handkerchief, to still further diffuse the light. In this condition the arms made one revolution in an average of 1·9 second. On shading the light from the south the time of revolution was 2·7 seconds. On shading it from the north the time was one revolution in 2·9 seconds. With the west shaded off it was one in 2·3 seconds; and with the east shaded off, the rate was one in 2·9 seconds.

The same radiometer, exposed near a south-east window in a room in the afternoon of the same dull April day, revolved once in 16 seconds.

[The radiometer shows a striking difference between heat and light, as commonly expressed. Brought into a uniformly *heated* space, the instrument comes to rest as soon as it has acquired the temperature of the space; but brought into a uniformly *lighted* space (151) it continues revolving as long as the light lasts.—Received January 10, 1876.]

152. The following experiments were tried with a very sensitive radiometer in a 2-inch bulb. The moving part (the "fly"), consisting of glass arms, pith disks, and steel point, weighed only 0·8 grain. It was exhausted with a charcoal reservoir attached (131).

A standard candle, placed 2 inches from the centre, made the arms spin with a velocity of 4 revolutions per second; with the candle 4 inches off the velocity was 10 revolutions in 11 seconds. In the full sunshine of a November day the speed was too great to count. Nothing was visible but an undefined nebulous ring, which became more or less distinct as the sunlight increased and diminished owing to passing clouds. This speed was kept up for more than an hour; indeed there appears no reason why it should ever diminish as long as light of uniform intensity shines on it.

153. The same radiometer was tried by the light of a candle, 4 inches off, behind different screens, with the following results:—

1 candle,	4 inches off,	naked flame		1·1	sec. for	1 revolution.
„	„	behind	thin white glass . . .	1·3	„	„
„	„	„	thick plate glass . . .	1·4	„	„
„	„	„	purple glass	1·5	„	„
„	„	„	dark red glass	1·5	„	„
„	„	„	pink glass	1·6	„	„
„	„	„	light yellow glass . . .	2·1	„	„
„	„	„	blue glass	2·5	„	„
„	„	„	orange glass	2·7	„	„
„	„	„	green glass	3·0	„	„
„	„	„	"eclipse" glasses (blue and orange, almost opaque to daylight)	4·0	„	„
„	„	„	7½ millims. of water in cell	6·0	„	„
„	„	„	solution chromate of potash, 7½ millims. thick .	6·0	„	„
„	„	„	solution bichromate of potash, 7½ millims. thick .	7·0	„	„
„	„	„	clear plate of alum, 5 millims. thick . . .	9·0	„	„
„	„	„	solution chloride of cobalt, 7½ millims. thick . .	12·0	„	„
„	„	„	sol. ferrocyanide of potassium, 7½ millims. thick	16·0	„	„

1 candle, 4 inches off, behind	sol. ammonio-sulphate of copper, $7\frac{1}{2}$ millims. thick	20·0	secs. for 1 revolution.
,, ,, ,,	sol. ferricyanide of potassium, $7\frac{1}{2}$ millims. thick	30·0	,, ,,
,, ,, ,,	sol. sulphate of nickel, $7\frac{1}{2}$ millims. thick . . .	35·0	,, ,,
,, ,, ,,	sol. sulphate of copper, $7\frac{1}{2}$ millims. thick . .	39·0	,, ,,

154. The instrument is thus seen to be capable of very extended use as a measurer of radiation of any desired kind. Unlike the instrument described in paragraph 135, it cannot be used for actually balancing one quality of light against another; and the method of taking an observation is not so accurate, for it is less easy to count revolutions per second or per minute than to observe the movement of a spot of light along a graduated scale. There are besides many causes which tend to interfere with the accuracy of the indications of this form of instrument. But, notwithstanding these drawbacks, I think the radiometer is likely to be a more popular form of light-measurer. It requires no adjustment, and is always ready to be observed, whilst there is a peculiar charm in using an instrument which is constantly in active work. With the exception of the comparison by balancing one light against another, all the observations mentioned in paragraph 140 can be taken with the radiometer, and it is besides capable of applications of its own. I will mention one, although others easily suggest themselves.

As the radiometer will revolve behind the orange-coloured glass used by photographers for admitting light into their so-called dark room, it is only necessary to have one of these instruments in the window to enable the operator to see whether the light entering his room is likely to injure the sensitive surfaces there exposed; thus, having ascertained by experience that his plates are fogged or his paper injured when the revolutions exceed, say, one in three seconds, he will take care to draw down an extra blind when the revolutions approach that number. In photographic operations a radiometer may be placed in some convenient spot near the object to be copied. Having ascertained, once for all, how many revolutions the instrument makes whilst a good negative is being taken, the operator need in future take no account of the variation of light, but simply expose for the same number of revolutions, with a certainty that his negatives will all be of the same quality.

For the more important work of gas-testing probably the bar-instrument already described (135) will be more valuable; although, even for this purpose, the radiometer will be found to give very rapid and trustworthy indications.

155. I have already mentioned that the motion of the radiometer depends on a differential action of radiation on the black and white surfaces. To obtain rotation in the ordinary way the black must be repelled with more energy than the white; and this appears to be the case with all the luminous rays. In the case of dark heat, however,

this difference of action is not apparent (128). The following experiments were tried with various radiometers:—

A candle was placed at such a distance from a radiometer that the fly would make one revolution a minute. A small glass flask of boiling water was then placed half an inch from the bulb. The revolutions instantly stopped, two of the arms setting equidistant from the hot-water flask. The candle was kept in the same position, and the flask of water was removed. As the portion of the bulb which had been heated by the hot water cooled, the white surface gradually crept nearer and nearer to it, the superior repulsion of the candle on the black disks urging the arms round, and acting in opposition to the repulsion of the hot glass to the white disk. At last the force of the light drove the white disk with difficulty past the hot spot of glass. Rotation then commenced, but for some revolutions there appeared to be a difficulty in the white disks passing the spot of glass which had been warmed by the hot water.

156. The flask of boiling water was then replaced in its position half an inch from the bulb of the radiometer. The rotation immediately stopped. The candle was then brought gradually nearer and nearer to the instrument, but with no particular effect. As it came very near the arms vibrated to and fro, and appeared to make violent efforts to get round, but no force of the light seemed sufficient to overcome the repugnance of the white disk to pass the heated portion of the glass.

157. The radiometer was allowed to cool, and the candle was again placed in the first position, where it produced one revolution in a minute. The finger was pressed against the side of the bulb. As the spot of glass got warm the white surface experienced more and more difficulty in getting past it, until at last one disk refused to pass, and the arms came to rest.

The instrument was again allowed to cool, and the revolutions recommenced at the usual speed (the laboratory in which this was tried was somewhat cold). I then came from a warm room, and stood a foot from the radiometer, watching it. In about a minute the radiant heat from my body had warmed the side of the bulb nearest to me sufficiently to cause an appreciable difficulty in the movement, and soon the revolutions stopped. The same effect has been observed if the radiometer is brought into a very warm room, and placed near a cold window. If the daylight is feeble, the instrument not very sensitive, or an observer stands near the instrument, an appreciable sticking is observed as the white disks come near that part of the bulb which is the warmest.

These experiments show that dark heat has quite a different action from that of the luminous rays. They also show that many precautions are necessary to guard against the interfering action of unequal heating of the radiometer when it is being used for accurate measurements.

158. Having found such an antagonistic action of dark heat, I tried the action of ice. This, I have already shown (33, 88), is equivalent to warming the opposite side of the instrument. A piece of ice brought near the radiometer on one side cuts off the influx

of heat to it from that side, and therefore allows an excess of heat to fall upon it from the opposite side.

The same radiometer that I used in the experiments with boiling water (155) was mounted with a candle the same distance off as before, so that one revolution took place in one minute. A lump of ice was now brought within half an inch from the bulb on the opposite side to the candle. The revolutions got slower, each arm as it passed seeming drawn towards the ice, and having a difficulty in moving away from it. At last the movement stopped altogether, an arm pointing direct to the ice, and being apparently held there by a powerful attractive force. Bringing the candle nearer caused the arms to oscillate a little; and when it was almost close to the bulb the force of the light overcame the action of the ice, and the arms revolved again, but irregularly and with jerks, the disks moving quickly to the ice and leaving it with difficulty. In this action of ice no preference was noticed for either the black or white surface.

159. A very delicate radiometer, in 2-inch bulb (152), was placed in a light just sufficient to see it distinctly by, but not enough to cause it to move. I then came out of a warm room and stood near it. In a few seconds it began to move slowly round, *but the motion was negative*, i. e. the black disks advanced instead of retreated—the action of the radiation of low intensity from my body being apparently to repel the white surface more than the black. On moving away from the instrument the rotation gradually stopped. I now came near it again, and held one hand an inch from the bulb. Rotation soon commenced, but still in the reverse way. These experiments were repeated several times and on different evenings with the same results.

160. When the instrument was at rest I came quickly to it, and gently breathed on the bulb. There was a slight movement in the normal direction, but this stopped directly, and the arms commenced to revolve the negative way, and kept on in the same direction for more than a minute, performing three or four complete revolutions.

161. A glass shade 4 inches diameter was held over a gas-flame till the air inside was warm and the inner surface dim with steam. It was then inverted over the radiometer. Negative rotation commenced, and kept up for several minutes.

The glass shade was then dried inside, and heated uniformly before a fire, until it had a temperature of about 50° C. It was then inverted over the radiometer. Negative rotation instantly commenced, and kept up with some vigour for more than five minutes, diminishing in speed until the shade had cooled down to the temperature of the surrounding air.

162. The same experiment was repeated, and whilst the arms were in full rotation a lighted candle was slowly brought near it. When 3 feet off the negative rotation slackened. When the candle was about 2 feet off the arms became still, and when nearer than 2 feet the instrument rotated normally. The antagonism between the action of the hot shade and the lighted candle was perfect; by moving the candle to and fro it was easy to cause the radiometer to move in one direction or the other, or to become still. These experiments were repeated many times, always with the same result. The perfect

obedience of the instrument to the opposing forces, according as one or the other was in excess, was very striking. I may mention that only some of my radiometers act in this manner. It seems to require extreme lightness and great perfection of vacuum. The movable parts of the radiometer which shows this action best only weigh 0·55 grain.

163. These experiments had all been tried with surfaces made of pith, a very bad conductor of heat. It became of interest to ascertain what would be the action of a radiometer the fly of which was made of a good conductor, such as a metal. Experiments already recorded show that metals behave generally like pith. This has been proved in the case of magnesium (99, 100), aluminium (122), silver and bismuth (63), copper (64), brass (37–40, 61), and platinum (55, 62, 113, 114, 115); but none of these experiments have been tried under the different conditions to which I have lately submitted the radiometers.

164. I selected thin rolled brass as the material wherewith to make the fly of a radiometer. The parts were all fastened together with hard solder, and no cement or organic matter was used, so that if necessary the radiometer could be submitted to a high temperature without injury. In general appearance when finished it resembles the instrument shown in fig. 6. The moving portion weighed 13·1 grains. One side of the disks was silvered and polished, the other side being coated with lampblack. The apparatus was exhausted with a charcoal reservoir attached. When exhausted it proved to be very sensitive, considering its weight, a candle $1\frac{1}{2}$ inch from the bulb causing it to revolve about once a second, the black surface being repelled in the normal manner.

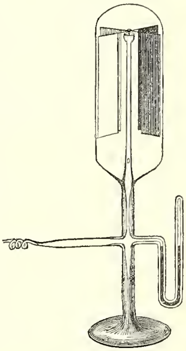
165. The apparatus, standing motionless in a rather dark cold room, was covered with a warm glass shade. It immediately commenced to revolve the negative way, viz. silver side repelled, but very slowly.

A few drops of ether poured on the bulb caused the arms to move rather rapidly the normal way. A hot shade put over whilst it was thus moving caused it to stop, and then begin moving the negative way.

A small non-luminous gas-flame was held vertically beneath the apparatus, so that hot air should ascend and wrap round the bulb on all sides. The arms now revolved the negative way.

166. The brass radiometer being somewhat heavy, one was made of aluminium, of the shape represented in fig. 9. The surfaces were made large, and the whole moving parts were hard-soldered together. A siphon-gauge was attached, and the apparatus was connected direct on to the pump by a spiral, no charcoal-tube being used. One side of the wings was bright aluminium and the other was lampblacked. When exhausted the fly revolved very quickly to a candle a few inches off, the black being repelled.

Fig. 9.



167. On removing the candle a remarkable phenomenon was observed. The arms stopped and immediately commenced revolving the negative way, keeping up rotation for more than ten minutes, and being little inferior in speed to what it was when the candle shone on it.

The whole of the bulb was heated with a BUNSEN burner; whilst it was getting hot the aluminium arms revolved rapidly in the normal direction; but as soon as the source of heat was removed and cooling commenced, negative rotation set up, and continued with great energy till the whole thing was cold. It appeared as if the negative movement during cooling was equal in amount to the positive movement as it was being heated.

168. The very sensitive pith radiometer used in experiments 152 *et seq.* was now experimented with. A little ether was dropped on the bulb as it was standing still in a faint light. The evaporation of the ether caused a chilling of the instrument and a rapid abstraction of heat from the fly. It commenced to move in the positive direction, and increased quickly in speed until it revolved at a rate of one in four seconds. This movement kept up for several minutes, and as it slackened it could at any time be revived by a few drops of ether on the bulb.

When in rapid positive movement, produced in the above manner, a hot glass shade (161, 165) was placed over the radiometer. The movement slackened, the arms quickly came to rest, and then immediately revolved in the negative direction, acquiring a speed of about two revolutions a minute, and keeping up this negative movement for more than ten minutes.

169. The radiometer was again set in rapid positive rotation by dropping ether on the top of the bulb. I applied the tip of one finger to the side of the bulb for ten seconds. The rotation stopped, and I could not start it again for some minutes, although I dropped ether on the bulb several times in the interval.

When the radiometer had once more acquired the temperature of the air, I dropped ether on the bulb, not in cethe ntre, but so that the ether wetted only half of the bulb. The arm which was nearest to the part most wetted by the ether rushed towards that part and remained, as it were, fixed opposite to it, refusing to move away, although I tried to equalize the temperature by dropping ether on the other parts of the bulb, and to drive it round by bringing a candle near. Not until the candle came within 6 inches of the bulb did the arms begin to rotate, which they then did with a rush, as if suddenly relieved from a state of tension.

170. These results appear at first sight anomalous. I think, however, they admit of an explanation which is in keeping with the facts, if I may make one supposition. The great difference between a lampblacked and a white surface is only an optical one. Pith reflects a considerable amount of light, and lampblack absorbs a large quantity of light, but it is unsafe to carry the analogy into the ultra-red region of the spectrum. We know of many white powders, optically identical, which in their thermic relations are as wide apart as pith and lampblack (*e.g.* powdered alum and

powdered rock-salt); and it is therefore reasonable to suppose that other substances may exist which, whilst they are very different to the eye, may have the same action on dark radiant heat. We may also fairly assume that a substance may exert a considerable selection on the rays which it absorbs and reflects—that, in fact, there may be, in the ultra-red region of the spectrum, *thermic* colours, as in the visible spectrum we have *optical* colours; so that whilst two substances may absorb to the same extent heat-rays of one refrangibility, they may be quite different in their actions on heat-rays of another refrangibility. These suppositions are not only resonable but very probable: let us see how they account for the facts. Light falls on the black and white surfaces of a radiometer, or other similar instrument. That which falls on the white surface is nearly all reflected back again. Were the surface perfectly white *all* the force which went into the bulb would be reflected out again; the incident ray would contain in itself a certain amount of potential work; but as the emergent beam would come out with no loss of intensity, no work could have been done on the reflecting surface. In practice this does not quite hold good. Pith is not a perfect reflector, some light stops behind, that which comes from it is not quite equal to that which it receives, and the balance makes itself evident by causing the pith to move to a slight extent.

171. But in the case of light falling on the lampblacked surface the result is very different. Here, practically, the whole of the light is quenched by the lampblack. Force is poured into the bulb, but none comes out. What, then, becomes of it? It is changed into motion, and becomes evident in the strong repulsion which is exerted on the black surface.

This I think is clear in the case of light. We can see that there is an enormous difference in the absorbing powers of white and black pith for light, and we can also see that there is an equally marked difference between the motive power which light exerts on them. But with the heat from boiling water or from a hot copper ball our eyes cannot tell us whether the same difference obtains or not, and we must use other and less direct means of finding out what takes place.

Let me direct attention to the experiments described in paragraphs 128 & 144. Here red-hot copper was seen to repel the black surface with violence, and the white surface only moderately. As the copper ball cooled, the repulsion on each surface became more nearly equal. At 400° C. the differential action was decided, though faint. At 300° C. the black surface was still repelled slightly more than the white surface, but at 250° C. down to 100° C. the repellent action of the radiant heat was the same on the white as on the black surface. The two surfaces were then *thermically* of the same colour.

The fact that the work done on each surface was equal, is, I think, proof that the absorption of the incident rays was equal.

172. Let me now carry the reasoning a step further. Experiments described in pars. 159 to 168 show that when heat of low refrangibility—from the body (159), the breath (160), hot air, or a warm glass shade (161, 165, 168)—falls on the white and

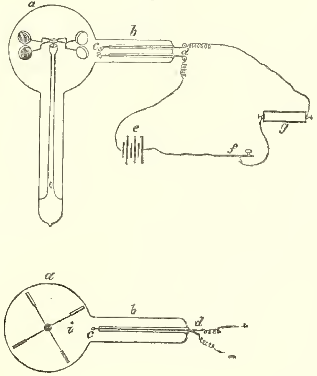
black surfaces, the white is repelled more than the black, rotation of the radiometer taking place in the negative direction. The same rays falling on the two surfaces do more work on the white than on the black; and this, to my mind, appears sufficient to make it almost certain that the white pith absorbs more of these low rays than does the lampblack.

173. Let us imagine that surfaces of lampblack and pith are carried along the spectrum from the blue to the ultra-red. As long as they are in the visible portion we observe an enormous difference between them. In the extreme red we can actually see that this difference is becoming less. In my mind's eye I picture the progress being continued along the whole length of the ultra-red spectrum. I can see, by the light of the above-quoted experiments, that the absorptive action of the two surfaces gradually gets more equal. Soon they become identical in their action on the incident rays, and after that they enter a portion of the spectrum whose rays are no longer absorbed by lampblack, whilst they are quenched by the pith. Lampblack and pith have now changed places; the latter is black, whilst lampblack has become a white substance.

174. The normal rotation of the radiometer caused by dropping ether on it (163) is perfectly well explained by the above hypothesis. If heat in the act of absorption produces motion in one direction, in the act of radiation it produces motion in the opposite direction (167). Heat of low refrangibility falling on the radiometer repels the white more than it does the black, and produces negative rotation. When the same kind of heat is drawn out of the black and white surfaces by the chilling action of the ether, movement takes place in an opposite direction, and the arms rotate normally. On stopping this efflux of heat by covering the instrument with a hot shade (163), I changed the direction of movement by causing the surfaces to absorb instead of emit heat.

An irregular emission or absorption of heat (164) stops the movement altogether, for the reasons given in pars. 155 to 158.

Fig. 10.



175. I have made an apparatus by means of which I hoped to put the above theory to accurate test. The results are not so definite as they ought to be in order to settle the question; but they are worth giving in detail, as some novel facts have been elicited by them.

Fig. 10 shows the instrument: *a* is the bulb of a radiometer of the usual construction, having pith disks blacked on one side. *b* is a tube sealed into one side of the bulb, and having two stout platinum wires passing along it, sealed their whole length in glass to prevent leakage of air into the interior of the apparatus. At the ends *c* of the wires, a spiral of fine platinum wire is fastened, and the other ends (*d*) terminate in loops outside. *e* is a battery, *f* a contact-key, and *g* a resistance-coil, which I can vary at will. The bulb was perfectly exhausted, and the following experiments were tried:—

176. The resistance-coil was so adjusted that the battery would keep the platinum spiral (*c*) at a bright red heat. The arms of the radiometer, which were before quite still, moved rapidly until two of the disks were one on each side of the hot spiral, the black disk being further off than the white disk, as shown at *i*. The resistance was then gradually increased, and as the temperature of the spiral diminished, the black disk gradually approached the spiral, until, when the temperature was just at the point of visible redness in a dark room, the black and white disks were practically equidistant from the spiral. On diminishing the resistance, the same phenomena took place in inverse order.

177. The resistance was adjusted to give a bright red spiral, and the contact-key kept pressed down. The disks stood as at *i*. A lighted match was momentarily brought near the bulb, so as to start a movement. Rotation of the arms commenced, and kept up, with some energy, at the rate of about 1 revolution in five seconds, equal to that given by a candle 8 inches off. There was some little hesitation as the white side came up to the spiral, but this was scarcely noticed when the speed had become steady.

The resistance was slightly increased. The speed became slower as the temperature of the spiral diminished, and the hesitation as the white approached the spiral became more apparent. The resistance was further increased, with the effect of making rotation still slower. I now brought the temperature of the spiral down to just visible redness in the dark. The speed of rotation again slackened; at each approach of the white surface to the spiral it stopped, hesitated, and then got past with a rush. Thus it went on for a few revolutions, until one white disk, a little nearer perhaps than the others, was not able to pass, and the arms after a few oscillations came to rest, the black and white surfaces being, as near as I could judge, equidistant from the hot spiral.

These results fully confirm those obtained in experiments 128 & 144, and I think justify the conclusions arrived at in my discussion of them at par. 171—that at temperatures between 250° and 100° the repellent action of radiant heat is about equal on black and on white surfaces.

178. I now wished to ascertain whether the continuation of the reasoning (172) was correct—whether at temperatures lower than 100° C. the white would be repelled most.

The resistance of the coil was increased again, and the position of the arms in respect to the spiral noticed. When so much resistance was offered to the passage of the current that the spiral would only be just warm, I fancied the white set further from it than the black; but the observation was not satisfactory at higher temperatures; up to visible redness the repulsion was equal for each.

The breath sent the arms rapidly round the negative way (160).

179. The battery was disconnected from the instrument, and one end of a wire was attached to one of the platinum loops, *d*, the other end of the wire being connected to the prime conductor of a frictional electrical machine. A few turns of the handle sent the arms flying about wildly; sometimes they spun round violently in one direction, then they stopped and went round the other way, finally one pointed steadily to the platinum spiral and refused to move. A candle was brought near, and all means were tried to discharge the disk, but with no effect. When the candle was quite close it overcame the interference, and the disks revolved in an irregular jerky manner.

The spiral was ignited by a battery, in the hope that this would discharge the electricity, but with no avail, and there was nothing to be done but stop the experiments and put the apparatus in water.

In three or four days the electrical disturbance was sufficiently diminished to enable me to proceed experimenting; but I could detect the influence for weeks after.

180. One pole of a small induction-coil capable of giving half-inch sparks in air was fastened to the platinum loops *d*, the other pole being held by an insulating handle. The loose pole was then brought near the bulb. The nearest disk rushed round to it and followed it a little, then it stuck as if the glass were electrified. By gently moving the loose pole round I could get the arms to rotate in either direction with a little practice, and they would keep on for five minutes or more when once started. It seemed a matter of indifference whether the black or the white surface went first. The results with the induction-coil were only a little more under control than those with the friction machine. The movements appear all to be explained by the known laws of static electricity; the rotations have no connexion with the instruments under the influence of radiation, but are of the "electrical fly" kind (34, 35, 36).

181. Before leaving the subject of the radiometer, it may be of interest if I describe a few forms of this instrument which I have made for special purposes.

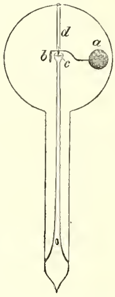
It is easy to get rotation in a radiometer without having the surfaces of the disks differently coloured. A radiometer was made similar to the one described in par. 152, but somewhat larger, and having the pith disks lampblacked on both sides. Its weight was 1·25 grain. It was exhausted with a charcoal-tube attached. When it was exhausted and a candle was brought near it, the arms moved until two of the disks were equidistant from the flame, and no amount of initial impulse in one or the other direction would set it in rotation. A piece of ice caused it to move until one disk pointed to the ice, when it also stopped. By shading the candle with a screen, so that the light shone on only one half of the fly, rapid rotation commenced, which was instantly stopped, and changed into as rapid rotation in the opposite direction, by altering the position of the screen to the other side.

182. It is difficult to exhibit the movement of a radiometer to any large number of people at once. To enable me to do this I have made an instrument, the disks of which are thin glass, silvered and polished on one side, and coated with lampblack on the other. This, owing to its great weight (65 grains), is somewhat slow; but in the

sun, or with the electric light shining on it, the movement is very striking, as it shows four disks of light chasing each other round the room.

183. A radiometer was made of the following construction (fig. 11). *a* is the disk of pith, black on one side; it is attached to a thin brass arm revolving on a needle-point; *b* is a mirror, seen in section, hanging from the other side of the brass arm, and having its plane perpendicular to the plane of the pith disk *a*. The needle-point works in a jewel cup *c*, and is prolonged upwards into the tube *d*, which is sealed into the bulb, and in which the needle fits loosely. Behind the mirror *b* is a very small magnet, to give direction to the arm. The object of having the upper tube (*d*) is to prevent the arm from coming off in carriage: with the four, or more, armed radiometers it is easy to get the movable part on when it falls off, but with this one-armed instrument it would be an almost impossible feat. (This artifice of an upper protecting tube is one I have had occasion to adopt on many occasions, and I find it very convenient.) The moving part weighs 2·42 grains; it revolves somewhat slowly when a candle is brought near, owing to the interference of the magnet. When the magnet is rendered nearly astatic by another magnet near it, and an index ray of light is reflected from the mirror, this radiometer is sensitive to a candle several yards off. It is a more convenient instrument for measuring different kinds of radiation than is the one on a similar principle described in par. 135, but, owing to the friction on the needle-point, it is not so sensitive.

Fig. 11.



184. A large radiometer in a 4-inch bulb was made with ten arms, eight of them being of brass, and the other two being a long watch-spring magnet. The disks are of pith, blackened on one side. The weight of the fly is 11·87 grains. This moves very rapidly for so heavy an instrument. The power of the earth on the magnet is too great to allow the arms to be set in rotation, unless a candle is brought very near; but once started it will continue to revolve with the light some distance off. This was made to enable me to communicate motion from the interior of the bulb to the outside. By suspending a magnet near the bulb, it oscillates to and fro with every revolution of the radiometer. The movement can thus either be projected on a screen or it may work a telegraphic instrument, and thus give a visible demonstration or a permanent record of the revolutions caused by any source of light under examination. As a self-registering photometric instrument this form of radiometer would be of considerable value.

185. A large six-disk radiometer was made in a 4-inch bulb. Immediately over the needle support a silvered glass mirror was fixed almost, but not quite, horizontal. By throwing a beam of light vertically downwards on this mirror it is reflected upwards at a slight angle, and as the radiometer revolves the movement can be seen by an audience as a spot of light traversing in a circle around the ceiling. The effect of various lights, coloured screens, &c. in modifying the rapidity of movement can be well illustrated in this manner.

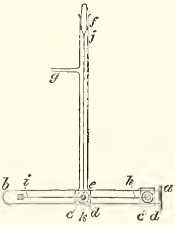
In a subsequent paper, which I hope soon to have the honour of laying before the Society, I propose to give the results of my experiments on the different rays of the solar spectrum, on the action of light and heat on various surfaces other than black and white, and on some attempts I have made to measure the force of radiation.

PART IV.

186. In a former paper on this subject, communicated to the Royal Society March 20, 1875, I gave some rough observations (110, 111) on the effect of the different rays of the electric and solar spectrum on the horizontal torsion-balance (102); and in a note (111) I said, "Every thing is ready to try a series of experiments with the solar spectrum, as soon as sunshine is available. The results shall be communicated in a subsequent paper."

The apparatus which I have now used for this purpose is shown in figs. 12 & 13. Fig. 12 shows the horizontal torsion-balance; it is similar in appearance to the one described in par. 102. $a\,b$ is a piece of thin glass tubing, sealed off at the end b, and ground perfectly flat at the end a. In the centre a circular hole (c) is blown, and another one (c') at the end, the centre hole being at the back, and the one at the end in front. The edges of these holes are ground quite flat. a, c, and c' can therefore be sealed up by cementing flat transparent pieces of plate glass, quartz, rock-salt, &c. (a, d, and d') on them. To the centre of $a\,b$ an upright tube ($e\,f$) is sealed, having an arm (g) blown on it for the purpose of attaching the apparatus to the pump. $h\,i$ is a glass index drawn from glass tubing, and as light as possible consistently with the needful strength. A long piece of this tube is first drawn out before the blowpipe, and it is then calibrated with mercury until a piece is found having the same bore throughout; the necessary length is then cut from this portion. $j\,k$ is a very fine glass fibre, cemented at j to a piece of glass rod, and terminating at k with a stirrup, cut from aluminium foil, in which the glass index ($h\,i$) rests. In front of the stirrup is a thin concave glass mirror, shown at k, silvered. The suspending thread is selected of the proper stiffness by the method given in par. 103. The small glass rod hung on to the end of the fibre to test its torsion weighs 15·46 grains; its length is 90 millims., and its external diameter 3 millims. The selected fibre, having this glass rod suspended to it in air, was found to vibrate half oscillations in 35 seconds.

Fig. 12.



The weight of the beam with the blackened pith ends is 0·891 grain; the mirror and stirrup by themselves weigh 0·87 grain; therefore the whole beam, as suspended, weighs 1·761 grain. The length of the beam from centre to centre of the pith squares is 147·5 millims. This beam is so light, and the pith surfaces are so large, that its vibration in air, when suspended from the glass fibre, cannot be timed. Therefore to ascertain what the torsion of the fibre is with that weight suspended on it, I cemented a piece of platinum weighing 1·543 grain (1-10th gramme) to the fibre, cut to the proper length, and timed its oscillations. 10 half-vibrations were taken by a chronograph. The times recorded during three experiments were

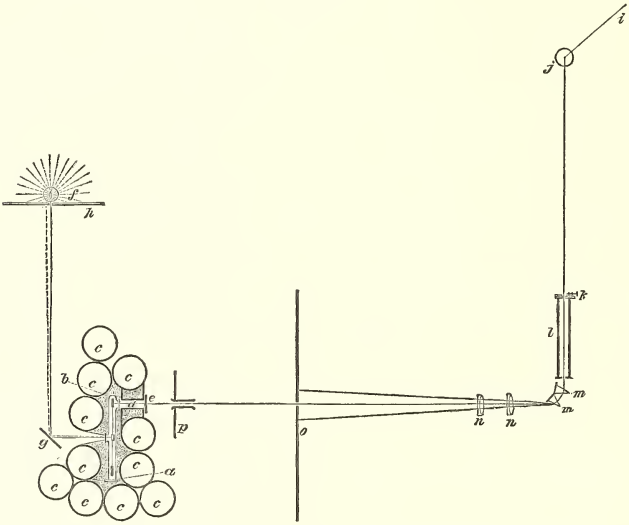
9·5 seconds, 9·6 seconds, 9·6 seconds;

so that *in vacuo* the beam ought to take about two seconds for each complete oscillation.

The pith surfaces at the ends of the beam are 13 millims. square; they are very thin, and are lampblacked on the surface. The window in the centre (*d*) is of plate glass, the window at *d'* is of quartz. They are on opposite sides of the apparatus, as will be better seen by referring to fig. 13.

187. When fitted up for spectrum observations the whole arrangement is shown in fig. 13. *a b* is the torsion-apparatus, shown in plan, the pith disks being represented by black lines at the ends of the central fine line representing the beam. The suspended mirror is shown in the centre of the beam. The quartz window is shown at the end *b*, and the other window opposite the central mirror. *c*, *c*, *c* are Winchester quart bottles full of water, and each encased in brown paper to prevent it accidentally acting as a lens, and condensing light on any part of the apparatus. Between the bottles, and surrounding the apparatus on all sides, as well as above and below, cotton-wool is well packed, spaces being left only for the rays of the spectrum to pass to the pith disk, and for the index ray of light to pass to and from the mirror. The cotton-wool acts as an excellent non-conductor of heat, and also prevents air-currents. The water in the bottles keeps the apparatus of a nearly uniform temperature, and entirely prevents sudden

Fig. 13.



changes. *d* is a cardboard tube, blackened inside, for the light to pass along; it has a movable shutter (*e*) at the outer end, which can be opened or closed by a touch of the finger without shaking the apparatus. The torsion-balance is firmly fastened to the walls of the room, which are very thick and firm, whilst the bottles and rest of the apparatus are supported by the floor; vibration caused by walking about or touching any of the other pieces of apparatus is therefore not communicated to the torsion-beam. *f* is a small lamp, a ray from which, passing through a narrow slit, falls on the inclined mirror (*g*), whence it is reflected to the suspended mirror of the torsion-apparatus. The light is now reflected back again to the mirror (*g*) and the graduated scale (*h*), where its position indicates the movements of the torsion-beam. The mercury-pump (not shown in the figure) is at some distance from the apparatus, so that the radiation from my body might not affect the apparatus when the pump was set working.

The ray of sunlight (*i*) falls first on the silver mirror (*j*) of a heliostat moving by clockwork; thence it is reflected to the slit *k*, along the tube *l*, through the prisms *m*, and the lenses *n*. *o* is a large screen, with a narrow vertical slit in it, so as to allow only the part of the spectrum I wished to experiment with to pass on to the apparatus. *p* is another screen extending for a considerable distance, and intended to prevent extraneous light from entering the apparatus when the shutter (*e*) is opened. It has a square aperture of such a size that a beam of light passing through it will just cover the pith surface (13 millims. square). The slit was kept half a millimetre wide during the experiments; the focus of the lenses was so adjusted as to form a sharp image of the spectrum lines at the place occupied by the square of pith on the torsion-beam. The slit and prisms are on a firm stand, capable of rotating through a small angle on a centre near the prisms. By this means any desired portion of the spectrum can be thrown on the pith without disturbing the focus. This necessitates an alteration in the adjustment of the heliostat, but that is soon effected. Slight alterations in the position of the spectrum can be made by moving one or both of the lenses sideways.

The distance between the slit and prisms is 16 inches; from the prisms to the pith surface is 7 feet 8 inches. The length of the spectrum here is 200 millims. from the lines A to G. The apparatus was fitted up in a room which admitted the sun in the right direction from about 10 A.M. to half-past 1 P.M. The heliostat was sufficiently good to keep a beam of light on the apparatus the whole of that time.

188. The past summer and autumn have been very unfavourable for spectrum researches of this character. My first accurate experiments with the above described apparatus were tried on July 26, and between that date and the middle of September the apparatus was kept in good adjustment, so that use could be made of the comparatively few occasions when the sun was sufficiently clear. I find that, owing probably to a variation in the aqueous vapour in the atmosphere or to slight haze, the observations of one day are not readily compared with those of another. Isolated experiments on one part of the spectrum are therefore of slight value, and my endeavour has been to embrace as wide an extent of spectrum each morning as I was able. A cloudless sky is not always the

clearest. The best results seem to be obtained when there is a moderate amount of wind, and great white clouds are floating about. The method of observation was as follows:—Having adjusted the scale so that the index ray of light pointed to zero, and having brought the particular part of the spectrum I wished to examine opposite the aperture in the screen, I opened the shutter and watched the progress of the luminous index until it reached its furthest point, when the shutter was closed. As the scale was divided into millimetres, the number of these traversed by the index was taken as the value of the part of the spectrum which shone on the pith. The piece of pith was 13 millims. square; consequently each number so obtained must be considered the average of a portion of the spectrum 13 millims. long.

189. I give below the actual results as they were obtained.

Date.	Portion of spectrum thrown on to pith*.	Deflection of index ray of light.	Observations.
		millims.	
July 26.	C	25	
"	D	19	
"	E	12	
"	b	8	
"	F	5	
"	between F and G†	2	
29.	C	61	
"	D	34	
"	b	12	
"	F	9	
Aug. 4.	A	23	Sky hazy, and light varying very much.
"	B	24	
"	C	35	
"	between C and D	27	
"	D	15	
"	b	10	
5.	between B and C	40	
"	D	29	
"	between D and E	24	
"	b	17	
"	F	10	
"	between F and G	6	
"	G	3	
"	H_1	2	
13.	ultra-red	147	The sun was very bright and powerful. All the observations were taken between 12 noon and 1 P.M.
"	"	121	
"	B	105	
"	between C and D	75	
"	" "	65	
16.	between A and B	96	Sun very bright. No clouds.
"	D	80	
"	between D and E	57	
"	b	33	
"	F	25	
"	between F and G	16	
"	" "	12	
"	G	5	

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* The lines were caused to fall on the exact centre of the pith. Consequently the action is caused by the portion of the spectrum 6½ millims. on each side of the portion here designated.

† The exact position of the central line falling on the pith was in this and similar cases carefully taken and marked on a diagram (see Plate 35. fig. 14).

TABLE (continued).

Date.	Portion of spectrum thrown on to pith.	Deflection of index ray of light. millims.	Observations.
Aug. 17.	just below A	90	Sun very bright, but small hazy clouds floating about.
„	C	65	
„	just above C	64	
„	D	63	
„	b	48, 42	
„	F	35	
„	between F and G	17	
„	G	11	
„	H	9	
31.	just below A	205	White clouds in patches. Sun occasionally obscured. Could not work after noon.
„	C	155	
„	between D and E	110	
„	„ „	85	
„	E	67	
„	F	40	
„	between F and G	13	
Sept. 1.	ultra-red	35	Sun very bright, but large white clouds floating about. Observations taken during clear intervals.
„	„	133	
„	„	170	
„	„	190	
„	„	127	
„	A	113	
„	B	102	
„	between C and D	79	
„	„ „	77, 75	
„	between D and E	59	
„	b	34	
„	F	23	
„	between F and G	14	
„	„ „	13	
„	„ „	12	
„	H	9	
10.	ultra-red	21	Sun quite bright up to 12.30 P.M., then the sky became rather hazy.
„	„	100	
„	„	169	
„	„	215	
„	C	149	
„	E	82	
„	F	29	
16.	E	88	Perfectly clear sky.
„	F	47	
„	G	18	
„	H	13	
„	ultra-violet	11	

190. In fig. 14, Plate 35, which is reduced to half the linear scale, I have attempted to show the above results graphically. The horizontal band, crossed by vertical lines, at the lower part of the figure represents the solar spectrum. The vertical lines to which letters are attached are the FRAUNHOFER lines. The other lines do not represent spectrum-lines, but are put there to mark the parts of the spectrum at which observations were taken. The spectrum is of half the length which I used in the experiments, and the lines are also to scale. The square black portion at the left extremity shows the relative size of the pith surface in the torsion-apparatus.

The dots scattered about the upper portion of the figure, when measured from the upper horizontal line bounding the spectrum, give the millimetres traversed by the index ray of light when the portion of the spectrum corresponding to the dot fell on the black pith. Observations taken the same day are connected by lines; the date of observation is written at the beginning and end of the line. The curves thus formed may be regarded, therefore, as a measure of the intensity of the radiation.

Although there is a general resemblance between the curves taken on separate days, inasmuch as they all approach a maximum at a point somewhat below A, and then diminish on each side, the incline being steeper on the ultra-red than on the blue side, yet there is scarcely any resemblance between the heights of the curves on separate days. There are two causes for this. The first is that the weather was not always so favourable as I could wish; but having waited so long, I took observations at first whenever I could get an opportunity. Thus the first four days, July 26 and 29, and August 4 and 5, were not quite clear, and the curves consequently have but slight gradients; they form a group by themselves. Afterwards I became more critical, and would not attempt spectrum observations unless there was a good chance of a very bright sun. Consequently the curves on the next three days, August 13, 16, and 17, show an improvement in altitude. Having got these results, I determined not to try any more unless the weather were exceedingly favourable, and then to work principally at the extreme ends of the spectrum. The curves of August 31, September 1, 10, and 16 show, in consequence, much greater elevations.

The second cause which may possibly account in some measure for the differences in the curves, is that, as the apparatus was kept exhausted week after week with the pump working almost daily, the pith may have become drier, the aqueous vapour may have become more perfectly removed, and the vacuum consequently more nearly absolute*.

191. To obtain the nearest approach to the theoretical curve of intensity from my results, it will not be right to take the mean of all my observations. The error can only be on one side—that of deficiency. Therefore the lower observations must be rejected, and the highest results only taken.

Bearing in mind that the spectrum formed with glass prisms is condensed at the red end and expanded at the blue end, it would appear from an inspection of the curves, that, with a normal spectrum, such as a diffraction-grating would give, the maximum of action should be at a little below A in the ultra-red, and that the curve should descend equally on each side.

192. This appears to be the most appropriate place to discuss the question which, from its being almost invariably asked the first, seems to be of the greatest interest to most inquirers:—"Is the effect due to *heat* or to *light*"?

I cannot answer this question. The terms heat and light are not definite enough. The physicist has no test for light independent of heat. Light and colour are physiological accidents, due to the fact that a small portion near the middle of the spectrum happens to be capable of affecting the retina of the human eye. There is no real distinction between heat and light; all we can take account of is difference of wave-length; and all we can see in the spectrum is one continuous series of vibrations, longer at the red end than at the violet end, but extending in an unbroken series for an unknown distance on each side. I say unknown, for it is probable that the whole spectrum, as we know it, is limited by the imperfect transparency of the atmosphere, or of the refracting medium, for the extreme ultra-red and ultra-violet rays.

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* I could not exhaust this apparatus with charcoal (131) owing to the cement joints.

Take a ray of the spectrum of a definite wave-length (the line B for instance), and allow it to fall on a thermometer; the mercury rises, showing the action of *heat*; concentrate it on the hand by a lens, it raises a blister accompanied with pain; let it fall on a bismuth and antimony couple, the galvanometer is deflected; and this action we also call one of *heat*. Let the ray fall on the eye, and it produces the sensation of *light* and *colour*. Let it fall on a collodion plate prepared in a particular manner, and it gives a permanent image, showing that it can cause *chemical action*. Lastly, throw the ray on a portion of matter free to move in a vacuum, and it makes itself evident as *motion*. Now these actions of *heat*, *light*, *colour*, *chemical action*, and *motion* are inseparable attributes of the ray of that particular wave-length; and to consider that there can be a splitting-up of this ray into two or more rays of the same refrangibility, one having the property of light, the other of heat, &c., is to my mind an absurdity.

The longer waves of the spectrum are those most able to produce heating-effects, the shorter waves best cause chemical action, and the intermediate waves easiest excite the sensation of vision; but although the maxima of these actions are at different parts of the spectrum, each effect can be detected at any part.

In a similar way the production of motion has its maximum in the waves situated at the ultra-red part of the spectrum, whilst it is capable of being rendered evident in all parts. This at first sight would favour the supposition that the action was due to the heating power of the waves.

193. How far this is really the case may be seen by the following Table, in which I have reduced the maximum to 100, and given the motion-producing value of the different colours of the spectrum, reduced in the same proportion:—

Ultra-red	100
Extreme red	85
Red	73
Orange	66
Yellow	57
Green	41
Blue	22
Indigo	$8\frac{1}{2}$
Violet	6
Ultra-violet	5

A comparison of these figures with those usually given in text-books to represent the distribution of heat in the spectrum will be a sufficient proof that the mechanical action of radiation is as much a function of the luminous rays as it is of the dark heat-rays.

194. In the intervals of spectrum work I tried many other experiments with the apparatus. I was anxious to get the exact time of the oscillations of the beam in a vacuum, and tried many ways of starting the initial impulse.

A candle held close to the screen, and the shutter momentarily opened and closed, sent the index with some violence to the extreme limit of the scale. It then slowly came back to zero and there stopped. Magnesium wire used in the same way produced the same effect. There was no oscillation, as there would have been if the impulse had been given by a material blow. The movement of the beam, as shown by the spot of light, seemed as if it were held in check by a force acting the whole time of its movement, and not only for the time the light acted. The impression conveyed was that the beam was swinging in a viscous fluid, and the more perfect the vacuum the greater appeared to be the viscosity (107). Thinking that the heat-rays from the candle might be absorbed by the black pith and so raise its temperature, I interposed screens of water, alum, and thick plates of glass, so as to cut off the ultra-red rays. Still the apparent resistance to free oscillation continued.

I then, without interfering with the vacuum, and without letting radiation fall on the pith surface, gave the apparatus a sudden twist round, so as to cause the beam to knock against the side of the tube. This set it swinging through a large arc, and the oscillations kept up with perfect freedom for several minutes, declining in amplitude at each oscillation till the beam ultimately came to zero. This perfectly free movement is in strong contrast to the constraint under which the beam moves when the initial blow is given by a ray of light instead of by a mechanical push.

The same effect was noticed during the experiments with the spectrum. A ray in the blue, falling on the pith, would drive the index twenty divisions along the scale. It would then gently come back to zero, where it would stop, occupying the same time to come back as it did to go forward. If, however, after the action of the light had entirely ceased, I gave the tube a slight jerk, so as to cause the beam to swing through the same arc, the index on returning to zero would pass perhaps 15 degrees the other side, and would thus oscillate for some time from one side to the other of zero, taking many minutes to come to rest.

195. This phenomenon enables me to advance a step towards an explanation of the mechanical action of radiation, although I fear I shall have to make some assumptions which are scarcely yet proved.

A ray of light falls on a white surface and is reflected back again; it does no work there (170, 171); but if the ray falls on a black surface it is absorbed and quenched. What becomes of it? It seems to me probable that the ray becomes converted into thermometric heat, and that its energy is in whole or in great part used up in raising the temperature of the dark body. But having thus become warm, the powerful radiating action of the surface for heat comes into play, and the heat, which has just been engendered and absorbed, is quickly radiated back again. It would appear as if this radiation of heat from the surface of a body caused the latter to retreat backwards, and so produced the motion. This would account for the apparent viscosity of the vacuum; for the heat radiating from the black surface of the pith would act in opposition to the torsion, and hold the latter force in check till it was itself all dissipated. The superiority of pith over metal is also accounted for. Pith is one of the worst conductors of heat, and thus allows all the heat to radiate from the same surface which absorbed it; whilst metals, being the best conductors of heat, allow it to pass through and radiate almost as much from one surface as the other.

The slight action of the blue rays is thus due to their short vibrations not being capable of transmutation into so much thermometric heat as are the longer rays; whilst the strong action of the red rays is owing to the degradation necessary to convert them into heat being but slight.

This action is parallel to that of the production of phosphorescence. A ray of such high refrangibility as to be invisible falls on a suitable surface; it is there absorbed, degraded in refrangibility, and radiated out again in the form of visible rays of longer wave-length. We have only to imagine our eyes to be unaffected by what we now call light, but capable of responding to an octave lower in the spectrum, and we should see the same thing when the blue ray falls on the blackened pith. In such a case an invisible beam would be thrown on a suitable surface of lampblack; the latter would instantly respond, lowering the refrangibility and increasing the wave-length to the point of visibility; the ray so generated would be absorbed and then radiated back again, the lampblacked surface glowing with light for some time after the original ray had ceased to fall on it.

196. Making use of the property discovered by Dr. TYNDALL of the almost perfect transparency for the invisible heat-rays of iodine dissolved in disulphide of carbon, and its opacity to the luminous rays, experiments were instituted with a view to obtain a numerical comparison of the mechanical action which was due to the invisible rays and that due to the visible rays.

The apparatus was used as fitted up for spectrum observations (187), the prisms and lenses being removed. A ray of sunlight was reflected from the heliostat, then reflected by means of a right-angled prism (placed in the usual position of the refracting prisms) into the apparatus.

The action of the sunlight was far too powerful for the apparatus, and I accordingly passed it through a plate of alum, a thick piece of glass, and an empty glass cell.

On opening the shutter the pith was powerfully repelled, the index ray moving 300 divisions. The cell was filled with disulphide of carbon, and the experiment again tried. The index moved to the same point.

The clear disulphide of carbon was removed, and it was replaced by a strong solution of iodine in disulphide of carbon. This was opaque to the sun's ray. On opening the shutter the deflection amounted to 79°.

This experiment shows that the total radiation from the sun, passing through alum and glass screens, produced a deflection of 300°, whilst if the whole of the light was cut off by interposing a solution of iodine in disulphide of carbon, there was still a movement of 79°. This 79° was the effect due to dark heat which penetrated the alum, the difference (221°) being due to light.

I endeavoured to cut off the whole of the dark heat, so as to work with the luminous portion only of the solar radiation. The ray of sunlight reflected from the heliostat was accordingly passed through the following screens, placed one behind the other, as shown in Plate 36. fig. 15:—

A lens.
A thick, total-reflection, right-angled prism.
Three thin plates of glass.
A plate of alum $7\frac{1}{2}$ millims. thick.
Two thick glass plates.
Another plate of alum, 5 millims. thick.
A glass cell full of saturated solution of alum.
An empty glass cell.

It was expected that these numerous cells would effectually cut off the dark heat-rays. To prove this the empty cell was filled with opaque disulphide*. On opening the shutter the deflection of the index was 2° only.

What came through the alum, glass, and water screens was therefore pure light, practically free from the dark rays which are called heat.

The opaque disulphide was then replaced by clear disulphide. The deflection was 105°.

	Action of filtered sunlight.
Opaque disulphide	2 degrees.
Clear disulphide	105 „

Deducting the 2° as representing the trace of dark heat which escaped the alum, glass, and water screens, the difference (103°) represents the action of the luminous portion of solar radiation and of that small quantity of the ultra-violet rays which would pass the screens; for had the effect of the sun's radiation after passing through the screens been due to *heat*, on cutting off the *light* by means of opaque disulphide, the deflection should have been practically undiminished. But experiment shows that, after passing through the screens, the repulsion due to heat is less than 2 per cent. of the total action of the solar ray.

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* For the sake of brevity I call the solution of iodine in disulphide of carbon *opaque disulphide*; the disulphide of carbon alone I call *clear disulphide*.

The screens, whilst diminishing the heat almost to nothing, also cut off a considerable quantity of the light.

197. A similar series of experiments was tried with the radiation from a candle. No alum, glass, or water screens were at first interposed, and the deflections were taken with the clear and opaque disulphide, alternately put in the path of the ray. The candle was 3 feet off. The mean of several experiments was as follows:—

Opaque disulphide	28 degrees.
Clear disulphide	130 ,,

This shows that much of the action of a candle is due to rays which pass through iodine, *i. e.* to the ultra-red rays.

The candle was now brought 2 feet from the apparatus, and the alum and glass screens were interposed. On repeating the experiments the mean result was as follows:—

Opaque disulphide	5 degrees.
Clear disulphide	37 ,,

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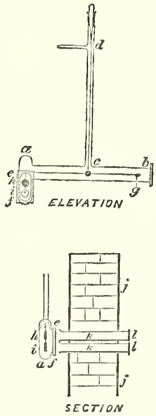
198. I have hitherto taken it for granted that a lampblacked surface is the most repelled by radiation, and that a white surface, such as that of freshly cut pith, is the least repelled. Experiments tried repeatedly with other surfaces abundantly confirm this supposition. It was necessary, however, to get accurate data on this point; and I have accordingly fitted up an apparatus which will enable me to measure the force of radiation and its action on disks of various materials of the same size, compared with a standard black disk.

The apparatus is represented in fig. 16. It is similar in principle to the torsion-apparatus already described (186). *a b* is the horizontal tube containing the glass torsion-beam; *c d* is the suspending fibre, also of glass. In the centre of the beam is a mirror, from which an index ray of light is reflected. The end *a* of the horizontal tube is sealed on to a wider piece of tube in a vertical position, and having in front of it a large opening (*e f*) occupying the whole of one side of the piece of tube; this opening has the edges ground perfectly flat, and is closed with a piece of plate glass cemented on. The object of the opening is to enable the disks to be changed. At the end (*b*) of the horizontal tube is another opening, closed in like manner with a plate of glass. This is to give access to the pan (*g*) of the beam, so as to counterpoise the disks, as they are not all of the same weight. At the other end of the beam a light aluminium bar hangs, on which is cemented the standard disk *h* and the movable disk *i*. The standard disk is of pith, coated with lamp-

Fig. 16.



black by holding it over the flame of burning turpentine. The movable disk may be of any substance.

The apparatus was fitted up in a recess built of brick, and closed in front with a glass window. In the brick wall at the side *j* holes were pierced opposite the disks and the central mirror. These were lined with card tubes (*k*) blacked inside. The interstices were packed with cotton-wool, and the apparatus was closely surrounded with Winchester quart-bottles filled with water. In front of the card tubes wooden shutters (*l*) were fastened, so that either one could be opened independently of the other. The apparatus was sealed on to the pump by means of the arm shown at the upper part of the torsion-apparatus.

With nothing in the pan, and only the standard black disk on, the beam is in equilibrium; consequently each new disk requires a special counterpoise.

199. The following weights and measurements of the different parts of the apparatus were taken:—

Weight of glass beam, central stirrup, and mirror	3·0485 grains.
Standard black disk and aluminium bar	0·4635 grain.
Pan at other end of glass beam, acting as counterpoise for above.	0·5263 ,,
Weight of white pith disk and support	0·2670 ,,
Counterpoise for ditto	0·3085 ,,
Length of arm from centre of support to centre of disk . . .	99 millims.
Length of arm from centre of support to centre of counterpoising pan	84 ,,
Diameter of disks	17·25 ,,
Torsion of suspending fibre, in air, with glass rod (186) hanging to it	½ oscillation in 15·75 seconds.

200. The experiments were tried as follows:—The exhaustion having been carried to the utmost point, so that no increase in sensitiveness was produced by further working the pump, a standard candle was adjusted opposite the black disk and at a definite number of millimetres off. The deflection of the index ray of light was then taken on opening the shutter. After completing this observation, the beam was allowed to come to rest; the candle was then lowered till it was opposite the lower disk, and the deflection caused by it was again taken. These were repeated several times. The mean results of the first series are given in the following Table (the lower disk being plain white pith):—

Distance of candle from disks.	Screen interposed.	Deflection of index ray of light on millimetre-scale 1100 millims. from mirror.			
		Black disk.	White disk.	Reduced to Black=100.	
				Black.	White.
800 millims......	Nothing	192	32	100	16·7
900 ,, ...	,, ...	122	21	100	17·1
1200 ,, ...	,, ...	62	10	100	16·1
500 ,, ...	Cell of water	80	7	100	8·7
500 ,, ...	Alum plate.....................	100	8	100	8·0
500 ,, ...	,, solution	76	7	100	9·2
500 ,, ...	Ammonia gas, 6 in. thick, and cell of water...........	79	7	100	8·8
800 ,, ...	Ammonia gas alone	190	31	100	16·3

201. The lower disk was removed and replaced by a disk of pith thickly coated on one side with pure precipitated carbonate of lead. The disk weighed 0·499 grain, the counterpoise weighing 0·530 grain.

After complete exhaustion, the results of various experiments are shown in the following Table:—

Distance of candle from disks.	Screen interposed.	Deflection of index ray of light on millimetre-scale 1100 millims. from mirror.			
		Black.	Carb. Lead.	Reduced to Black=100.	
				Black.	Carb. Lead.
800 millims.	Nothing	130	17	100	13·0
500 ,, ...	Iodine in disulphide of carbon	127	9·5	100	7·5

Instead, therefore, of carbonate of lead being a good absorber of the rays which produce motion, it is a better reflector than a plain white pith surface, owing probably to its superior whiteness.

202. Another black surface was now sought for to compare with the standard disk. Pith coated with precipitated iodide of palladium was employed. The disk weighed 0·460 grain, and the counterpoise 0·491 grain. The results were:—

Standard Black.	Iodide of Palladium.	Reduced to Black=100.	
		Black.	Iodide of Palladium.
70	61	100	87·3

203. Plates of alum and of rock-salt were successively introduced into the apparatus, to be compared with the standard black disk. The apparatus was, however, not sufficiently sensitive to enable me to make satisfactory comparisons. The average of

several observations (which, however, were not so concordant as I should have liked) were—

Standard Black.	Rock-salt.	Reduced to Black=100.	
		Black.	Rock-salt.
131	4	100	3

Standard Black.	Alum.	Reduced to Black=100.	
		Black.	Alum.
120	6	100	5

There was no action on either the alum or the rock-salt when a screen of water or of alum was interposed.

204. In consequence of some experiments tried by Professors Tait and Dewar, and published in 'Nature,' July 15th, 1875, I fitted up a more sensitive apparatus for the purpose of carefully examining the action of radiation on alum, rock-salt, and glass. The apparatus was similar to the one described in par. 186, there being, however, no window at either end. To the horizontal beam suspended by the glass fibre were attached a plate of alum at one end and a plate of rock-salt at the other. Each plate was perfectly polished and transparent, and measured 12·5 by 13·5 millims., and was 1·5 millim. thick. The deflection was produced by a candle placed opposite the crystalline plate under examination, and it was measured in the usual way by a reflected ray of light. The following were the results:—

Distance of candle from plate.	Deflection observed.		Reduced to alum=100.	
	Alum.	Rock-salt.	Alum.	Rock-salt.
150 millims.	21	17	100	81
" "	22	17	100	77·3
" "	24	17	100	71
100 "	48	30	100	62·5
" "	43	26	100	60·4

The action on the alum was found to increase at each observation. A glance at the plate showed the reason. When it was first put in it was perfectly smooth and transparent. Before it had been long in the vacuum efflorescence commenced, and when the first observation was taken the surface of the alum plate was dotted over with small white specks, which increased in size and number as the experiments were continued. The opacity thus caused was apparently sufficient to account for the increased action of radiation upon the alum plate.

The pump was kept going the whole time, so that the water vapour evolved from the dehydrating alum might be carried away and prevented from interfering with the results, as it otherwise would have done (130). The last two experiments, however, show the effect of aqueous vapour.

205. To test the accuracy of the explanation that the opacity caused increased action, I coated two disks of pith, one with powdered rock-salt and the other with powdered alum, and tested them against lampblacked pith in a similar apparatus to the one described in par. 198. The deflections were—

	Black pith.	Powdered alum.	Powdered rock-salt.
	110	38	18
or reduced,	100	34·5	16·3

As will be seen on reference to par. 203, the ratio between the black disk and the plate of rock-salt was 100 : 3. Powdering the rock-salt has therefore increased the action 13·3 per cent. The much larger action of the powdered alum is probably due to the fact that crushing the crystals facilitates efflorescence *in vacuo*.

206. The alum and rock-salt plates were removed, a fresh alum plate ground and polished, and this and the rock-salt were coated with lampblack. They were then put into the apparatus as before, the black side being away from the source of radiation, so that the rays would have to pass through the crystal plates before meeting with the lampblack. The deflections were taken as soon as the vacuum was good. The deflections were—

	Blackened alum.	Blackened rock-salt.
	26	19
or reduced,	100	73

The rock-salt was more slow in its movements under the influence of radiation than the alum was, but they both returned to zero equally well.

207. A very sensitive apparatus, similar to the torsion-apparatus described in par. 198, fig. 5, was now employed, and a clear polished disk of rock-salt and a thin disk of glass of the same size were placed therein. The apparatus was very well exhausted, and the deflections taken when the radiation from a candle was allowed to fall on either disk. The mean of several concordant observations was—

Rock-salt.	Glass.
39	40

I quote the following from the article in 'Nature' already referred to:—"Prof. DEWAR then proceeded to show that the heating of the disk was the efficient cause of the action. Two equal disks, one of rock-salt, the other of glass, were attached to the glass fibre. The rock-salt was inactive when the beam [from a candle] was thrown on it; the glass disk was active. The reason is evidently that the rock-salt is not heated, being transparent to heat, whereas the glass is opaque, absorbs the heat and is heated." It will be seen that I have failed to obtain this marked difference in action between rock-salt and glass, although the glass shell of the apparatus was as thin as was consistent with strength to resist the atmospheric pressure.

208. The action of radiation on surfaces of pith coated with thin layers of different substances is deserving of considerable attention. I have had an apparatus at work for several months past, in which six disks can be experimented with on the same beam and during the same exhaustion (similar to the arrangement described in par. 198, which held two disks). With this I have tried many hundred experiments, using the flame of a candle direct, or shaded by screens of water, alum, &c. The results are of much value, as showing that there is no definite connexion between the colour of a body and the mechanical action of radiation upon it. For instance, taking the movement of the lampblacked pith, under the influence of a standard candle, as 100°, I find that under the same conditions

Precipitated silver	moves	56°
Amorphous phosphorus	,,	40
Sulphate of baryta	,,	37
Red oxide of iron	,,	28
Scarlet iodide of mercury and copper	,,	22
Lampblacked silver	,,	18
White pith	,,	18
Rock-salt	,,	6·5
Glass	,,	6·5

These are only a few of the results I have obtained. The experiments will occupy some time to carry out with the completeness which they deserve, and I therefore propose to defer any further mention of them to a subsequent paper.

The Measurement of the Force.

209. I have long endeavoured to devise some means of measuring the amount of force exerted by radiation, from a standard candle for instance at a foot off, on a measured surface of matter. The data given in pars. 199 and 200 are sufficient to enable the amount of force acting on the pith disks to be calculated indirectly; but I wished to have a means of measuring the force by as direct a method as we have of getting the weight of a ponderable body. I wanted an apparatus which will give me, at once, the pressure in grains which a ray of light exerts on a surface on which it may fall. Such an apparatus is shown in fig. 17.

The principle of the construction is that of the torsion-balance first described by W. Ritchie, F.R.S., in 1830*. *a b* is a glass tube 13·5 inches long, 1 inch wide as far as *a c*, and 1·2 inch wide at *c b*. It is closed at the end *a*, and ground flat and polished at the end *b*, so as to be capable of being closed by a plate of glass cemented on. *d e* and

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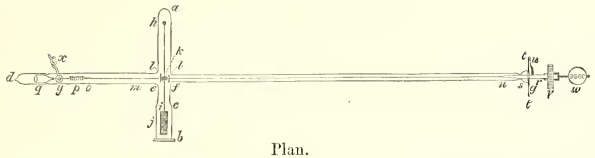
* Phil. Trans. vol. 120 (for 1830), p. 215.

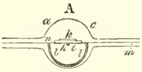
Fig. 17.



Plan.

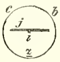
Elevations and details.

A



Vertical section of cross tube at the centre.

B



Vertical section of cross tube at the end containing the pith.

f g are two narrower tubes sealed into *a b*, as shown, the part *d e* being 17 inches long, and *f g* 38 inches long. *d e* is $\frac{1}{2}$ an inch in diameter, and is closed at the end; *f g* is a $\frac{1}{4}$ of an inch diameter. *h i* is a thin glass beam, having a glass weight at the end *h*, and a flat surface of lampblacked pith (*j*) at the end *i*. The pith (*j*) exposes exactly 2 square inches of surface. It is prevented from curling up in the vacuum by cutting it partly through at intervals, as shown. *k* is a silvered mirror, cemented on to the centre of the glass beam; *l l* are two knife-edges of glass, finely ground and polished; *m n* is a very fine fibre of glass cemented to the beam (*h i*) beneath the mirror (*k*). The end (*n*) of the glass torsion-fibre is attached to the solid stopper (*r*), which is carefully ground and polished into the contracted part of the tube (*s*). The other end of the torsion-fibre (*m*) is cemented to a filament of silk (*m o*); this silk is attached to one end of a steel spring (*p*), which is held firmly at the other end by the solid rod (*q*) cemented to the glass tube (*d e*). The torsion-fibre (*m n*) passes over the knife-edges (*l l*), which thus support the beam. The tension of the spring (*p*) is so adjusted that the glass fibre shall remain stretched under a constant pull of about 100 grains. *t t* is a circular card cemented to the end of the tube (*g*) and divided into 360 degrees. On the stopper (*r*) is fixed a pointer (*u*), which revolves with it, and marks the degrees through which it has turned. The complete revolutions are recorded on a "counter" (*w*). Motion is given to *r* by a torsion-handle (*v*). The apparatus is connected to the pump by the spiral (*x*), which works in a stopper tap (*y*) most ingeniously devised by my friend and assistant Mr. C. H. GIMINGHAM, so as to enable the instrument to be disconnected from the pump and attached to it again without interfering with the exhaustion*.

The stopper (*r*) is very accurately ground and polished in the tube at *s*, as long a surface as possible being in contact. It should be lubricated by setting fire to a piece of plain india-rubber, and allowing the melted drops to fall on the contact surfaces.

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* I have asked Mr. GIMINGHAM to send a description of this tap, and some useful improvements he has introduced in the mercury-pump, to the Royal Society.

This is a nearly perfect lubricant, allowing very free movement and preventing any access of air.

210. The torsion-fibre must be selected with great care. Ten threads were drawn (103) and were suspended from a horizontal beam. Weights were then gradually hung on to the lower ends. Only two were found strong enough, the others having broken before 450 grains had been added. The one selected stood 450 grains without breaking. Its diameter is less than ·001 inch.

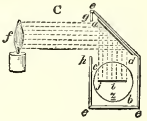
The torsion of the glass fibre was taken by the method given in par. 186. With the weight of 15·46 grains hanging on to it half an oscillation took 30 seconds.

A fellow thread, selected of as nearly as possible the same strength and tension, and having a weight of about 100 grains at the end, broke when it was twisted 36 times. The actual thread used in the balance has been tested up to 30 turns without breaking.

211. A flat oblong piece of soft iron, weighing accurately 0·01 grain, is put loose into the cross tube under the pith surface (see *z*, fig. 17, vertical section of cross tube). This weight can be picked up by a horseshoe magnet outside the tube, and dropped on any part of the pith. A mark is made at the exact centre of the pith surface, and by moving the magnet about, it is easy to place the iron weight accurately on this mark.

212. A silvered glass mirror is supported at an angle of 45° over the pith surface, and so that the centre of the mirror is 2 inches from the pith when the beam is in equilibrium. The whole is enclosed in a blackened box, in such a manner that when a candle is placed a few inches from the mirror in a horizontal line with its centre, no direct ray, but only the reflected ray, falls on the pith. Fig. 18 shows the arrangement: *a d* is the mirror; *e e e e* is the wooden frame with the aperture (*g h*) in front to allow the flame of the candle (*f*) to fall on the mirror and thence be reflected on to the pith without illuminating the pith with direct rays. *b c* is the cross tube, *j* the pith, *i* the beam, and *z* the iron weight.

Fig. 18.



213. A ray of light from a lamp is directed on the small central mirror (*k*, fig. 17) of the beam, whence it is reflected back to a millimetre scale 4 feet off, forming a sharply defined image, and making evident by its movement the slightest angular motion of the beam. When the reflected ray points to zero on the scale, it is evident that a turn of the torsion-handle (*v*) in one or the other direction will raise or depress the pith end of the beam, and thus cause the index ray to travel along the scale to the right or to the left. It is also evident that if a small weight is placed on one end of the beam so as to depress it, and the torsion-handle be then turned, the tendency of the glass fibre to untwist itself will ultimately balance the downward pressure of the weight, and (provided the glass torsion-fibre does not break) will bring the beam to a horizontal position, the index ray again pointing to zero. The object of the spring *p* is to keep the torsion-thread always stretched; and the silk fibre (*m o*) connecting the torsion-fibre and the spring is to allow the whole of the torsion of the fibre to be utilized in moving the beam, as the filament of silk may be considered practically free from torsion.

214. The first operation was to ascertain the number of degrees of torsion which were equal to the $\frac{1}{100}$ of a grain weight. The apparatus being well exhausted*, the index ray of light being at zero, and the pointer of the torsion-handle standing at 0° on the divided circle, the iron weight was picked up by a magnet, and placed exactly on the centre of the pith surface. The end of the beam instantly fell down, and I had to turn the torsion-handle 27 complete revolutions and 353° in addition, or 10073°, before the beam became horizontal and the index ray again stood at zero†. The downward pressure of $\frac{1}{100}$ of a grain was therefore equivalent to the force of torsion of the glass thread when twisted through 10073°.

215. My next operation was to find out the degree of delicacy of the balance. The law of torsion is that the force with which the glass fibre tends to untwist itself is directly proportional to the number of degrees through which it has been twisted ‡. I can therefore find out the smallest amount of weight which the balance will indicate by ascertaining what is the smallest angular movement of the torsion-handle which will cause an appreciable movement of the index ray of light.

I found that a movement of three degrees of torsion sent the index ray a considerable distance. One degree of torsion gave a very decided movement, whilst half a degree displaced the index ray to a sufficient extent to be easily seen. I believe less than half a degree could have been detected had the scale been further off; but not to run any risk of over-estimating the delicacy of the balance, I will take one degree of torsion as its ordinary working limit.

To what fraction of a grain will this torsion of one degree be equivalent? This is easily calculated. A twist through 10,073° balances the $\frac{1}{100}$ of a grain; a twist of 10,074° overbalances it.

$$10{,}073^\circ : 0{\cdot}01 \text{ grain} :: 10074^\circ : 0{\cdot}01000099 \text{ grain};$$
$$\therefore\ 10{,}074^\circ - 10{,}073^\circ = 0{\cdot}01000099 \text{ grain} - 0{\cdot}01 \text{ grain},$$
$$\therefore\ 1^\circ = 0{\cdot}00000099 \text{ grain}.$$

The balance will therefore turn to the $\frac{99}{100{,}000{,}000}$ of a grain.

Divide a grain weight into a million parts, place one of them on the pan of my balance, and the beam is instantly depressed!

216. The balance was exhausted up to the highest point, the index ray of light was projected on to the scale, and the apparatus was kept in darkness, well protected from external influences by screens around it. The index ray soon became stationary; it was then brought to zero, and the pointer of the divided circle set to 0°, the counter also being at 0.

A standard candle was then adjusted 10 inches from the centre of the mirror, and therefore 12 inches from the surface of the pith. The screens were removed, and the reflected rays of the candle were allowed to fall perpendicularly on to the pith surface. The pith instantly sank to the bottom of the tube, and the torsion-handle had to be turned through 442° to restore equilibrium.

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* This preliminary testing the value of the $\frac{1}{100}$ grain weight can be equally well performed in air.

† This is the mean of several concordant experiments.

‡ Biot, Traité de Physique, tom. i. p. 486; Ritchie, Phil. Trans. vol. 120. p. 215.

The $\frac{1}{100}$ of a grain required 10,073° of torsion to restore equilibrium (214); and the ratio between the weights being the same as that between the degrees of torsion, the mechanical force of the radiation from the candle is easily calculated:—

$$10,073^\circ : 0·01 \text{ grain} :: 442^\circ : 0·0004387 \text{ grain}.$$

Other experiments were tried, the candle being blown out and the apparatus allowed to cool in the dark between each. The following Table gives the results:—

Mechanical Force of Radiation from a candle on 2 square inches of blackened pith.

Distance of candle from pith.	Degrees of Torsion.	Mechanical Pressure.	Difference of last column from mean.
12 inches	442°	0·000438 grain.	−0·000006 grain.
,, ,, ...	449	0·000445 ,,	+0·000001 ,,
,, ,, ...	452	0·000448 ,,	+0·000004 ,,
Mean	448	0·000444 ,,	
6 inches	1815	0·001801 ,,	+0·000029 ,,
,, ,, ...	1800	0·001787 ,,	+0·000015 ,,
,, ,, ...	1740	0·001727 ,,	−0·000045 ,,
Mean	1785	0·001772 ,,	
6 ins., with water-cell interposed .	235	0·000233 ,,	

The pressure at 12 inches off is 0·000444 grain, whilst that at 6 inches is 0·001772 grain. At half the distance the pressure should be four times, or 0·001776 grain. The difference between theory and experiment, being only 4 millionths of a grain, is a sufficient proof that the indications of this instrument, like those of the previously described apparatus, follow the law of inverse squares.

The last column in this Table, the "difference from mean," shows that my estimate of the sensitiveness of this balance is not excessive, and that in practice it will safely indicate the millionth of a grain.

217. I have tried in vain to get a good observation with sunlight. On the very rare occasions within the last few months on which the sun has been shining brightly my balance has not been in adjustment, or I have been away from home. I was able, however, on December 13th last to get a few observations. The sun was obscured by thin clouds and haze, and its rays were but faint. The pressure of its radiation was, on this occasion, only equal to that of 10·2 candles, six inches off, pressing down the pith, therefore, with a weight of 0·018074 grain.

218. But the result of my observations of the sun on Dec. 13th being only equal to 10·2 candles 6 inches off, is of course far below the real power of the unclouded midsummer sun. I propose trying this experiment under more favourable circumstances. Meanwhile I have endeavoured to find what results in this direction have been obtained by other observers. The data given by different authorities vary considerably, as will be seen by the following Table:—

Baugee[*] found that sun = 62,280 candles 1 metre off.
Wollaston[†] ,, ,, = 59,830 ,, ,, ,,
Becquerel[‡] ,, ,, = 50,000 ,, ,, ,,
Zöllner[§] ,, ,, = 154,500 ,, ,, ,,

In these cases the sun was measured when at the highest point in a clear sky, and the *optical* difference alone was taken. In my case the light was very faint and hazy, and the total radiation, both of the sun and of the candle, was measured. I do not give my results as attaching the least importance to the actual figures, but simply as an illustration of the marvellous sensitiveness of the instrumental means at my disposal. I hope during the forthcoming summer to work out the subject more fully, and to be in a position to communicate to the Society many observations obtained with the torsion-balance, not only in photometry and the repulsion caused by radiation, but in other branches of science in which the possession of a balance of such incredible delicacy is likely to give valuable results.

Postscript.—January 17, 1877.

In the foregoing paper, pars. 126, 128, 155, 156, 157, 158, 159, 170, and 171, experiments are referred to which show that the repelling force appears to be different on a white or a black surface according as the radiation causing the movement is dark heat (from the fingers, hot water, hot glass, or copper below 250° C.) or the luminous rays. In commenting on these results, I gave what appeared at the time to be the most reasonable explanation. Twelve months' research, however, has thrown much light upon these actions; and the explanation afforded by the dynamical theory of gases makes what was a year ago obscure and contradictory, now reasonable and intelligible.

In a preliminary notice submitted to the Royal Society, Nov. 16, 1876, and published in No. 175 of the 'Proceedings,' I gave the explanation of the movements of repulsion under the influence of radiation according to the dynamical theory of gases, first, I believe, used in this connexion by Mr. Johnstone Stoney. In this preliminary notice I brought forward experimental proof that the presence of residual gas is the cause of the movement of the radiometer, and generally of the repulsion resulting from radiation, the maximum effect being at a pressure of about 50 millionths of an atmosphere. According to the dynamical theory of gases, the repulsion is due to the internal movements of the molecules of the residual gas. When the mean length of path between successive collisions of the molecules is small compared with the dimensions of the vessel, the molecules rebounding from the heated surface, and therefore moving with an extra velocity, help to keep back the more slowly moving molecules which are advancing towards the heated surface; it thus happens that though the individual kicks against the heated surface are increased in strength in consequence of the heating, yet the number of molecules struck is diminished in the same proportion, so that there is equilibrium on the two sides of the disk, even though the temperatures of the faces are unequal. But when the exhaustion is carried to so high a point that the molecules are sufficiently few and the mean length of path between their successive collisions is comparable with the dimensions of the vessel, the swiftly moving, rebounding molecules spend their force, in part or in whole, on the sides of the vessel, and the onward crowding, more slowly moving molecules are not kept back as before, so that the number which strike the warmer face approaches to, and in the limit equals, the number which strike the back, cooler face; and as the individual impacts are stronger on the warmer than on the cooler face, pressure is produced, causing the warmer face to retreat.

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[*] Essai d'optique sur la gradation de la lumière, 1729, p. 30.

[†] Phil. Trans. vol. 89, 1799.

[‡] Ann. de Chim. et de Phys. 3 série, t. lxii. p. 34, 1861.

[§] Private letter to the author.

This theory explains very clearly how it was that I obtained such strong actions in my earlier experiments when using white pith as the material to be repelled, and employing the finger as a source of heat, and how it happened that I did not discover for some time that dark heat and the luminous rays were essentially different in their actions on black and white surfaces. The explanation of this is as follows:—Rays of high intensity (light) pass through the wall of the glass vessel without warming it; they then, falling on the white surface, are simply reflected off again; but falling on the black surface they are absorbed, and, raising its temperature, produce the molecular disturbance which causes motion. Rays of low intensity (dark heat) do not, however, pass through the glass to any great extent, but are absorbed and raise its temperature. This warmed spot of glass now becomes the repelling body, through the intervention of the molecules rebounding from it with a greater velocity than that at which they struck it. The molecular pressure, therefore, in this case streams from the inner surface of the warm spot of glass on which the heat-rays have fallen, and repels whatever happens to be in front of it, quite irrespective of the colour of its surface.

XIV. *On the Development and Succession of the Poison-fangs of Snakes. By* CHARLES S. TOMES, *M.A. Communicated by* JOHN TOMES, *F.R.S.*

Received December 28, 1875,—Read February 3, 1876.

IN two papers which described the development of the teeth of Batrachia, Sauria, and Ophidia, which were laid before this Society, and appeared last year in the Philosophical Transactions, I gave a brief *résumé* of the literature of the subject, so far as it was then known to me. Between the dates of the reading of my paper and of its appearance in the Philosophical Transactions, Dr. HERTWIG, of Jena*, published a paper on the development of the teeth of Amphibia, in which the figures and the descriptions conform, in most essential particulars, with those accompanying my own paper. Although Dr. HERTWIG does not include in his remarks the groups Sauria and Ophidia, I have gladly taken this opportunity to acknowledge his independent and practically contemporaneous publication of results nearly identical with my own.

As I have so lately summarized the opinions of other observers upon the development of reptilian teeth (*cf.* Phil. Trans. part i., 1875), it will not be necessary for me to recapitulate them again in this paper; but I may be allowed to pass directly to the peculiarities which mark the development of poison-fangs.

At the conclusion of my paper on the development of Ophidian teeth, I remarked that there were noteworthy peculiarities in the formation of poison-fangs, which, for the want of material, I had not been able to make out in all their details. Since that time, by the kindness of my friends Prof. GARROD and Mr. ROBERTSON, of Oxford, I have been enabled to unravel what was before obscure; and the peculiarities of arrangement disclosed will, I venture to hope, be deemed of sufficient interest to justify me in laying them before this Society.

Of poison-fangs Prof. OWEN (Art. "Odontology," 'Encyclopædia Britannica') says:— "In the posterior part of the large mucous sheath of the poison-fang the successors of this tooth are always to be found in different stages of development; the pulp is at first a simple papilla, and when it has sunk into the gum the succeeding portion presents a depression along its inferior surface, as it lies horizontally with its apex directed backwards. The capsule adheres to this inflected surface of the pulp, and the introduction of the duct of the poison-gland is completed by the extension of the borders of the inflected pulp around that tube."

Exception might be taken to several points in this description; but as in my two earlier papers, and in a third, published in the first part of the Philosophical Transactions for this year, I have discussed the qualifications which need to be made before we can accept Prof. OWEN's description of the development of these or any other reptilian teeth, I have simply quoted his words here, as embodying what is commonly known of the development of poison-fangs.

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* Archiv f. mikros. Anatomie, Supplementheft 1874 (December).

Venomous snakes are divided into two groups—the *venomous colubrine snakes*, in which the poison-fang is attached to a fixed maxillary bone, so that it is always erect, and the *viperine snakes*, in which the maxillary bone carries no other teeth than the poison-fang, and is capable of a rotary motion, by which its fang is erected or laid recumbent (GÜNTHER'S 'Reptiles of British India,' Ray Society, p. 165).

I have had better opportunities of investigating the poison-fangs of the viperine snakes than of the venomous colubrines, of which latter the cobra is the only one which I have been able to procure in a perfectly fresh condition; but, as I shall presently show, there would appear to be well-marked differences in the succession between the two groups*. The relations of poison-fangs to their successors may be most advantageously studied in transverse sections, the specimens having been previously hardened and decalcified in chromic acid.

The appearance presented will vary, according as the section is near to the tip or to the base of the fang. I will commence by the description of a section taken midway in the length of the poison-fang of a rattlesnake (Plate 37. fig. 2).

The figure embraces that which would appear to the naked eye as an elevation when looking into the mouth of the snake—that is to say, the recumbent tooth covered in by its loose fold of mucous membrane (*c* in the figure) and the subjacent region where lie the successional teeth. At the upper part of the figure the poison-fang at present in use (1) is seen lying in a chamber in the mucous membrane, and since it is recumbent and parallel to the long axis of the jaw, it is in transverse section. Beneath it (or, as it would stand in the snake's mouth, above it) are a series of eight teeth of various ages, all seen in transverse section, the oldest lying nearest to the tooth already in use.

The successional teeth are not arranged in a single series, as would be the case in the ordinary serial teeth of the jaws (*cf.* my paper in Phil. Trans. 1875), but in a double row, being obviously placed in pairs.

A more careful inspection of one of these pairs will disclose that although there is no very great difference, yet one of the teeth is a little more advanced than the other. Thus in fig. 2 No. 2 is a little more advanced, both in development and in position, than No. 3, and is the tooth destined to be the next to move into its place and enter upon work. Lower down in the series this difference in point of development is less apparent; indeed the two constituting a pair are generally advanced to about the same stage in their construction.

I have affixed numbers to the several tooth-germs shown in figs. 1 and 2 to indicate the order in which they would succeed to the tooth already in use. It will be seen that the new tooth comes alternately from either side, No. 2 being on the left- and No. 3 on the right-hand side in fig. 2. There is an obvious advantage in such an arrangement, since it insures the least possible loss of time between the shedding-off of one poison-fang and its replacement by another; but if the new tooth passed exactly into the position of its predecessor little or nothing would be gained. Such is not the case, however; there is room upon the surface of the maxillary bone which gives attachment to the poison-tooth for two teeth, side by side (see fig. 4). The tooth actually in use occupies one side, where it is anchylosed by its base, side, and front, whilst its successor is getting ready to take possession of the vacant place by its side. Thus one poison-fang occupies the innermost position possible on the maxillary bone, the next one the outermost, and so they go on alternating. It will at once be obvious that such an arrangement of the successional poison-fangs is admirably adapted for securing a speedy replacement of a lost tooth; and sections taken near to the base of attachment almost invariably (unless it so happens that the attached tooth has only just become fixed and its predecessor but just shed off) show a second tooth (2 in fig. 4) which is in the process of attachment by the rapid development of a coarse bone (*b* in the figure) about its base.

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* I have examined several specimens of *Hydrophis* which were preserved in spirit, and believe the arrangement of the successional teeth to be similar to that observed in *Cobra*; but specimens long kept in diluted spirit are ill-suited for such investigations.

In fig. 2 (1) the tooth in place alone occupies the chamber in the pouch of mucous membrane which covers in the recumbent poison-fangs, all the successional teeth still remaining bedded in the mass of loose connective tissue in the midst of which they are developed.

In fig. 1, however, a different stage in the process is represented; it is taken from a section of the head of an English viper, in which I was so fortunate as to hit upon the moment, so to speak, of the change from an old tooth to a new one. The chamber in the mucous membrane is seen to contain sections of *two* teeth, which are separated from one another by a flap of connective tissue (*b*). This flap of connective tissue, visible also in fig. 2, is continuous with the slightly specialized connective tissue which lies between and separates the two series of successional teeth; and an apparent use for it is very obvious, though only actual observation can determine whether it has any other. It would seem probable that it serves to keep the advancing tooth to its own side, as it would be almost impossible for a tooth of the one series to get round it and so become wrongly placed on the side appropriated to the other series; it would also serve, by limiting the space in which the advancing tooth lies, to keep it straight—that is to say, to prevent it from diverging to the one side or the other in its own length.

In fig. 1 the tooth already used (1) is about to be cast off, and its successor (2) has already passed out of the region where teeth are being developed, and is doubtless becoming rapidly attached. In fact fig. 4 is a section from the very same specimen, though, unfortunately for the comparison, the section has been mounted with the other surface uppermost, so that the sides are transposed. However, 2 on the left of fig. 4 is the very same tooth as 2 on the right of fig. 1, the first-named section being taken close to its base, by which it will be anchylosed to the maxillary bone, this process being in fact already commenced *.

The development of poison-fangs in two parallel series, the teeth being arranged in pairs of almost equal ages, would suggest that the succession is very rapid and quite regular; were it not so, one would expect to find that the teeth of one series would be very markedly in advance of their fellows in the parallel series, which is not the case. Moreover the large number of successional teeth (ten) is unusual. I know of but one other place where more than three teeth can be found in preparation to succeed a single tooth, and that place is in the jaws of Ophidia, where six or seven of the ordinary serial teeth, in different stages, may sometimes be seen.

I believe that the development of poison-fangs in two parallel series would be found to be the rule, if indeed it be not universal, in viperine poisonous snakes. I can only positively answer for the English viper, the puff-adder, and the rattlesnake, these being the only poisonous snakes of this group which I have obtained quite fresh. But, judging from the vacant spaces by the side of the attached poison-fangs in macerated skulls, the arrangement holds good in all viperine snakes that I have seen.

The region where teeth are being developed in a *colubrine* venomous snake, the Indian cobra, is strikingly different. There is no double series, but the successional teeth are disposed in a single series, just like the teeth of a harmless snake, or the mandibular or pterygoid teeth of a poisonous snake. In fact the description which I gave in a former paper of the manner in which the teeth of the harmless Ophidia are developed would apply strictly to the poison-fangs of a cobra, save only that the individual tooth-germs are modified to form canaliculated teeth.

In fig. 5 there is seen a line of inflected epithelium (*g*) running in from the oral epithelium (*a*); this, which goes to form the enamel-organs of successive germs, is lost sight of behind the first successional tooth-germ ($_2$); its free extremity, already slightly dilated near where it will form a fresh enamel-organ, is seen at *f*. The section, having been taken a little behind the erect poison-fang already in use, shows no trace of this; but sections including the working tooth do not in the cobra show much of its successors, which lie behind it and are recumbent, whilst it is erect. The new tooth occupies more nearly the same spot as its predecessor than is the case in the Vipers.

It is, I think, a legitimate inference that the cobra, having lost one poison-fang, would remain unarmed for a longer period than a viperine snake, in which latter the new tooth is able to get into place and be ready to be fixed before the loss of its predecessor. May this not explain the preference shown by the Indian jugglers† for the cobra as a snake for snake-charming exhibitions? A cobra deprived of its poison-fangs would remain harmless for some little time, but a rattlesnake similarly disarmed would sooner replace its lost weapon.

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* Dr. WEIR MITCHELL ("On the Venom of the Rattlesnake," Smithsonian Contributions, 1861) had become aware that the succession was regular, and that the new tooth came up by the side of the old one; he did not, however, arrive at a correct interpretation of the positions and movements of the successional teeth as they are developed and rise into place.

† Snake-charmers do, however, sometimes make use of viperine snakes, *e. g.* the Tic Polonga (*Daboia Russellii*).

The colubrine poisonous snakes are less specialized than those of the viperine type; the maxillary bones are immovable, and are not very short; they also often carry a few other teeth behind the poison-fang. It is interesting to see that this lower degree of specialization is found in the processes of development and succession, so that the region in which the successional poison-fangs are being formed is strikingly similar to that in which the ordinary ophidian teeth are developed, whilst in the viperine snakes it is strikingly dissimilar and highly specialized.

To return to the consideration of the tooth-forming region of the vipers. I have shown that the teeth are developed in two parallel series, separated by a connective-tissue partition, which is prolonged so as to hang as a free fold (*b* in figs. 1 & 2) into the pouch occupied by the working tooth, and that the new tooth is taken from the one or the other series alternately. The successional teeth are arranged in two straight lines in the rattlesnake (fig. 2) and in two curved lines in the viper (fig. 1); but at another point in the rattlesnake's head the lower successional teeth are arranged along a slight curve, so that this difference is not of any moment.

The appearances presented by the tooth-forming area differ according as the section is taken near to the base or near to the tip of the working tooth. Close to the maxillary bone we see either the bases of two teeth, as in fig. 4, or the base of one tooth and the vacant space just vacated by another, as would be seen if we had a section at the base of the teeth represented in fig. 2. A little further down we have the state of things represented in fig. 3 (also from the same viper as figs. 1 & 4), in which the bases of four teeth are seen, which may be identified and compared with those in the other figures by their numbers, whilst as we approach nearer to the tip of the working tooth as many as ten teeth come into view.

Nearer to the tip of the active tooth we have passed beyond the region where tooth-development is most active, so that figs. 1 & 2 may be taken as giving the best idea of the parts. In order to make the relations of the several teeth to one another clear, I have constructed the diagram fig. 12 (p. 382), which is intended to show the positions of the transverse sections which have been figured on Plate 37; an actual drawing of a longitudinal section would not have answered the purpose so well, as the several teeth are so close together as to appear confused.

It now remains to give a short account of the structure and development of the individual teeth, and of the manner in which they become attached. The earliest tooth-germ is not distinguishable from that of any other tooth. A band of epithelium, which may be seen at *f* in figs. 1 & 10, grows out into the connective tissue beyond the youngest germ; its extremity becomes converted into an extinguisher-like enamel-organ covering over a newly forming dentine pulp. A transverse section of such a young germ is shown in fig. 6, and at $_8$ and $_9$ in fig. 2. The dentine pulp is surrounded by a thin

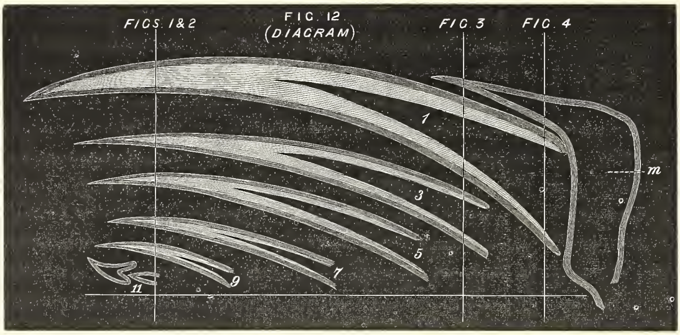

Fig. 12.—A diagram constructed from a comparison of many longitudinal sections. An inspection of this serves to explain why figs. 1 & 2 show in transverse section as many as ten teeth, while sections nearer the base, *e. g.* figs. 3 & 4, show but four and two teeth respectively.

layer of formed dentine, and outside this comes a continuous layer of enamel-cells (internal epithelium of the enamel-organ). A little later on, as the tooth-germ elongates, a shallow depression appears on the one side (fig. 8) into which the layer of enamel-cells runs without break; the groove deepens, but at first the enamel-cells do not undergo any modification (see fig. 7) in that groove which is to become the canal for the conveyance of the poison.

But at a later stage, when the crescentic pulp, with its layer of formed dentine around it, has arched round so that its extremities are approximating (fig. 9), a most remarkable change has taken place in that part of the enamel-organ which lines the groove. No distinct layer of enamel-cells can any longer be traced, but the whole space included in the concavity of the crescent is occupied by a mass of branched cells, which in their general aspect strongly recall the stellate tissue or reticulum which forms so large a part of mammalian enamel-organs. And as it is beyond all question that the enamel-organ, destined to play no active part in this concavity or canal, has become transformed into a sort of stellate tissue, are we to regard the stellate tissue of a mammalian enamel-organ as a retrograde metamorphosis of a superfluous tissue? Before becoming acquainted with the enamel-organ of a poison-fang I was aware, and had expressed an opinion, that the stellate tissue was quite non-essential, for there are many enamel-organs which form enamel of perfect structure and appreciable thickness which have never possessed any parts save their external and internal epithelium.

Ultimately this stellate tissue seems to wither up and leave the canal empty, so that we must regard it, in this place at all events, as a step on the way towards the disappearance of the enamel-cells; and as it is hardly to be found in advance of the thin edge of calcified dentine, it does little more than fill a void. A thin layer of enamel is formed round the exterior of a poison-fang; but after what has been said, I need hardly say that no enamel lines the interior of the poison-canal.

There is nothing noteworthy about the dentinal pulps of poison-fangs; but their manner of attachment to the bone merits a word or two of notice.

Looking with the naked eye at the bone which carries the poison-fangs, to which they are anchylosed by their bases, there is seen to be a sort of hood or parapet of bone rising up in front of the fangs. This would appear to add to their strength, as the tendency of the blow struck by the snake would be to displace the tooth forwards. This parapet of bone is seen in section in fig. 4 and fig. 3 (*m*). The firm attachment of the tooth is likewise secured by the form of its own base, which is convoluted (see figs. 4 & 5) and recalls the structure of labyrinthodont teeth at that point in the crown where their complexity of structure first commences; this convolution of the dentine at the base of a tooth which is attached by anchylosis is quite common in the teeth of both fishes and reptiles. The dentine interdigitates with the supporting bone, the line of junction consisting of a cloudy opaque calcified tissue, in which, without the use of acids, no definite structure can be seen. Immediately outside this there is very coarse bone, with very large irregular lacunæ, which gradually merges into the regular fine-textured bone of the snake's jaw.

When the new tooth is about to become attached, a sort of network or scaffolding of new bone is thrown out, which meets and interdigitates with the convoluted dentine, which is being simultaneously calcified. This new bone, coarse in texture and very rapidly developed, springs up outside the tooth-sac, and takes its origin from the surface of the old bone; it constitutes that "bone of attachment" to which I have elsewhere called attention as being invariably present where a tooth becomes fixed in place by the process of anchylosis. This "bone of attachment," present in large quantity both in the cobra and in viperine snakes, is specially developed for every tooth, and is removed when the tooth is shed, a fresh scaffolding being put forth for its successor.

The duct of the poison-gland was formerly supposed to become enclosed within the tube of the poison-fang by the process of the latter growing around it. This, however, does not happen; for that part of the tooth in which the groove has its lips closed, so as to form a tube, is completed before the tooth moves into place upon the maxillary bone.

That portion which is not thus completed is very short, and is impressed by an open groove only. Moreover the new tooth comes by the side of the old one, and does not occupy the same spot, so that such an arrangement would be all but impossible.

The poison-duct opens close above the base of the tooth, where the groove in which the upper end of the poison-tube terminates is situated. The close apposition of the hood of mucous membrane which covers the poison-fangs in secures a large proportion of the poison passing down it, but no more absolute communication than this takes place. In longitudinal section the remnant of the enamel-organ within the tube has a superficial resemblance to a duct within the tooth, and by this I was at first deceived. Examination of specimens in more perfect preservation, however, has rendered me certain that no sort of duct with soft walls exists within any part of the tube in the poison-fang.

Description of the Plate.

PLATE 37.

The same lettering applies to all the figures.

1. The poison-fang at present in use.
2. The tooth which stands next in order to replace the one in use.
3. The third in order of succession, &c.

a. Epithelium of the mouth.
a'. Epithelium continued into the pouch.
b. Connective-tissue septum, which serves to keep to their respective sides the teeth of the two parallel series when they move into position.
c. Section of pouch of mucous membrane which covers in the poison-fangs whilst recumbent.
d. Formed dentine.
e. Enamel-cells of the enamel-organ.
e'. Enamel-cells in the groove which is to become the canal for the conveyance of the poison.
f. Process of epithelium passing beyond the youngest tooth-germ, from which the next enamel-organ will be formed.
g. Band of epithelium connecting the tooth-germs with the epithelium of the surface.
h. Space in which the poison-fang lies whilst at rest.
k. Coarse "bone of attachment."
m. Maxillary bone.
n. Transverse bone.
p. Dentinal pulp.

Fig. 1. From English viper.

Transverse section of poison-fang and its nine successors. The tooth in use (1) is on the point of being replaced by a successor (2), which has already passed from the region in which it was developed into the cavity of the pouch. Between the two lies the connective-tissue flap, which helps to guide it into place, to keep it to its own side, and to keep it straight. Beneath these two teeth are eight successors arranged in pairs in two parallel series, the new tooth being taken alternately from either side.

On the right (*f*) is a process of epithelium from which a new enamel-germ would be formed; the corresponding epithelial process of the left-hand series of teeth is not clearly visible.

The position of this and some of the other sections will be better understood by a reference to the woodcut, fig. 12 (p. 382).

Fig. 2. From a full-grown rattlesnake.

A section in most respects similar to fig. 1, with the exception that the tooth in use (1) is not to be replaced so speedily as the corresponding tooth in fig. 1. The partition (*b*) is deflected to one side, there being only one tooth free in the pouch.

Fig. 3. English viper.

This section is taken from the same specimen as fig. 1, but through a spot nearer to the fixed base of the tooth (see Diagram, fig. 12, p. 382).

At the top of the figure is seen in section the parapet of bone which stretches up from the body of the maxillary bone in front of the teeth.

2, 3, 4. Portions of three successional tooth-germs occupying the remaining space between the parapet of the maxillary and the transverse bone.

Fig. 4. English viper.

From the same specimen as figs. 1 & 3; taken through the attached base of the poison-fang (1).

It is to be noticed that there is room for two poison-fangs, side by side, and that these two positions are alternately occupied by the working teeth.

The tooth 2, which is rapidly becoming attached, will be fixed in place by a framework of coarse bone (*k*), which shoots out from the maxillary bone and becomes united with the dentine.

Fig. 5. Indian cobra.

Transverse section, immediately behind the poison-fang.

The successional teeth come to occupy the same spot as their predecessors, and are developed, unlike those of viperine snakes, in a single series.

Compare this figure with that of the successional teeth of a harmless snake (Phil. Trans. part i. 1875).

Fig. 6. Transverse section of a very young tooth-germ from an English viper.

It does not differ as yet in any particular from the tooth-germ of any other Ophidian tooth.

Fig. 7. Viper. Tooth-germ a little older.

The groove, to become afterwards a canal, has commenced, but as yet the enamel-organ occupying it is not altered from that surrounding the rest of the tooth.

Fig. 8. English viper, at a somewhat later stage.

Fig. 9. English viper, later stage.

The enamel-organ occupying the interior canal has become transformed into a tissue of stellate cells (e').

Fig. 10. Process of epithelium, *f* (enamel-germ of Kölliker), from which a yet younger enamel-organ will ultimately be formed; at *e*, *d* is seen the youngest tooth-germ as yet actually formed.

XV. *On the Variations of the Daily Mean Horizontal Force of the Earth's Magnetism produced by the Sun's Rotation and the Moon's Synodical and Tropical Revolutions.*

By J. A. Broun, *F.R.S.*

Received December 15, 1875,—Read January 27, 1876.

History of the Investigation.

In a discussion of observations of the Bifilar magnetometer made at Makerstoun in 1844 a series of remarkable oscillations of the daily mean horizontal force were remarked, which, as the maxima occurred near new moon, and the minima near full moon, were attributed to the synodical revolution of our satellite*. This conclusion was afterwards confirmed by the result of four years' observations†. Kreil had found that the time of vibration of a horizontal needle was less near new moon and during the first quarter than near full moon and during the third quarter: this result he found only in the eight months November to June; while he obtained just the opposite result during the four months July to October‡.

In a much later investigation he found that his observations during the years 1842 to 1847 confirmed the result obtained by me, but that those for 1840 and 1841, and 1848 and 1849, were opposed to it, the magnetic force being greatest at full moon§. This change of law appeared to him connected with the decennial period.

An examination of observations made under my direction at Trevandrum in the years 1855 and 1856, and of other series, induced me to doubt whether the oscillations seen in the Makerstoun observations for 1844 could be explained by the lunar action. The appearance of maxima at full moon in similar oscillations in the observations of other years, the great amplitude of the oscillation and its nearly equal magnitude at different points of the earth's surface, induced me to seek for another cause. The only other apparent, with a period approaching that of the oscillation referred to, was the sun's synodic rotation on his axis. Kreil had already thought of this cause as an explanation of the different results obtained for the moon's action in summer and winter‖: this he considered might be due to the different solar poles presented to the earth at these two times of the year; but he soon perceived that any action due to the sun's rotation would be nearly the same in the means for the two seasons, since the time required for a synodical rotation of the sun and revolution of the moon differs by upwards of two days, and the annual law of force obtained by him showed a maximum in June and a minimum in December. KREIL then relinquished this idea, and sought for the explanation in the difference of the meridian altitude of new moon, which is low in winter and high in summer, his results showing a greater horizontal magnetic intensity for the moon south than for the moon north of the equator. This latter result for the moon's declination did not accord with that afterwards obtained by me from the Makerstoun observations[*].

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* Trans. Roy. Soc. Edinb. vol. xvi. part ii. p. 106 (read January 5, 1846).

† Ibid. vol. xix. part ii. p. xxxvi.

‡ Philosophical Magazine, vol. xvi. p. 241 (1840).

§ Wiener Denkschriften, B. v. S. 36 (1852). It was only after the results of the present paper had been obtained that I became acquainted with this memoir.

‖ Phil. Mag. vol. xvi. p. 241 (1840).

Although an examination of the Trevandrum observations confirmed me in the belief that the sun's rotation was the great cause of the variations of daily mean horizontal intensity, yet trials for the greatest mean oscillation, employing periods of a few tenths of a day more or less than 27·2 days (the time given then by the best authorities for the sun's synodical rotation), were not satisfactory[†], and the more complete investigation was deferred till the discussion of a longer series might enable me to draw more certain conclusions. Meanwhile, having found that the observations made at Trevandrum in 1844 and 1845 showed almost exactly the same variations as at Makerstoun, I returned to the examination of the observations made during these two years, and deduced from them, and from the observations made simultaneously in different Colonial observatories, that the mean duration of the oscillation was 25·96 days[‡]. This period differed so much from that then accepted for the sun's rotation that I suggested some movement, regular or irregular, of the sun's magnetic poles or of the meridian of maximum force [§].

In 1871 Dr. HORNSTEIN deduced from his observations at Prague in 1870, by calculation and graphic interpolation, a period 26·33 days, but varying from 26·0 to 26·7 days according to the instrument or method employed in the investigation. The mean period agreed almost exactly with that which had then been obtained by SPOERER for the sun's synodical rotation from spots in the equatorial zone. This result, brought to the notice of the Royal Society, Nov. 16, 1871, by the Foreign Secretary, and referred to in two presidential addresses, was the subject of a note in the 'Proceedings' of the Society (vol. xx. p. 417, June 1872). In a postscript to this note the following passage occurs:— "In my paper on the Horizontal Force of the Earth's Magnetism, I stated that 'a careful investigation of a much larger series of observations leads me to believe that the period is variable within certain limits' [‖]; whether this variation is due to a change of the solar meridian producing the maximum after certain intervals, or to superposed regular or irregular causes, I hoped, and hope yet, to determine."

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[*] Trans. Roy. Soc. Edinb. vol. xix. pt. ii. p. xxxvi.

[†] Writing from memory, I have previously said "26 to 27 days" were tried; this was a mistake. Proc. Roy. Soc. xx. p. 418 (1872).

[‡] Trans. Roy. Soc. Edinb. vol. xxii. p. 543.

[§] Phil. Mag., Aug. 1858. I think there is little doubt that KREIL would have discovered the variations of the earth's magnetism due to the sun's rotation if he had not believed that period to occupy nearly the same time as the moon's tropical revolution. My own belief that the oscillations observed by me were due to this cause in spite of the difference of periods, was founded on the comparison of observations in both hemispheres, where the agreement seemed inexplicable by the lunar action alone.

[‖] Trans. Roy. Soc. Edinb. vol. xxii. p. 544.

One of the most marked objections to the constancy of the solar action for given solar meridians for any considerable period was to be found in the middle of the series of well-marked oscillations for 1844. In the months of January to April there were four successive movements with periods of from 25 to 29 days, each having amplitudes of about one thousandth of the whole horizontal force; in the months of May, June, and July the oscillation may be said to have disappeared, while in the following months the movement reappeared as distinctly as in the first months of the year. It is the principal object of the present communication to show that this apparently anomalous result is due to the joint actions of the sun and moon.

Solar and Lunar Actions.

On a reconsideration lately of the results obtained by me previously for the moon's synodical revolution from four successive years' observations at Makerstoun, it seemed extremely improbable that they could be wholly explained by an action having a period of 26 days. Since in a discussion of a year's observations nearly 14 periods of 26 days and 12 of 29·53 days are employed, if the solar action remains the same for each period the maximum must have happened at nearly all the positions of the moon, and should have an equal effect at all epochs in the discussions relatively to the revolution of our satellite. If the moon's position had no effect on the magnetic variation, any result which might be obtained could be due only, as was supposed in this case, to irregularity in the solar action, and would certainly be different in the discussion of observations made in successive years. Some difference there was without doubt; but a reconsideration of the whole results has induced me to conclude that the agreement was too great to be explained by any other hypothesis than that of a conjoint action of the sun and moon.

The simplest method of determining the truth of this supposition was the following:—To obtain from the observations for a given time the mean variations due to each of three periods (namely, that of 26 days supposed due to the solar rotation, and those of 29·53 and 27·3 days due to the lunar synodical and tropical revolutions), to assume that these mean results represent the solar and lunar actions during each period (or that the action of each body remains constant for the same position) throughout the whole number of periods included in the investigation, and to obtain the variations of horizontal force for each day of the year by their addition. Such a construction will show to what extent the assumption is well founded.

In order, however, that this construction may be as accurate as possible, the mean results obtained for each body must be free from the effects due to the others. For this investigation we have the following equalities:—

Lunar synodical period	$15\times29\cdot53=442\cdot95$ days.
Solar	$17\times26\cdot0=442\cdot0$,,
Lunar tropical	$20\times27\cdot3=546\cdot0$,,
Solar synodical	$21\times26\cdot0=546\cdot0$,,
Lunar synodical	$12\times29\cdot53=354\cdot36$,,
Lunar tropical	$13\times27\cdot3=354\cdot9$,,

As the projected observed daily means of the horizontal force for 1845 show a more frequent action of irregular disturbing causes than those for 1844, the discussion has been made separately for the two years.

In the calculations for the lunar synodical and tropical periods, 12 of the first and 13 of the second were taken; as these occupy the same time, the effects due to the one are eliminated in the calculation for the other (constancy of law being always assumed). This is not the case, however, with reference to the solar period of 26 days, for which 14 periods were taken.

Since it requires 17 and 21 periods of 26 days for the elimination of the effects due to the lunar synodical and tropical periods respectively, if we seek the mean result for the solar rotation from 14 periods (=364 days) corrections must be applied on account of lunar actions not eliminated. Let $1', 2', 3' \ldots\ldots 26'$ represent the mean values of the horizontal force for the 1st, 2nd, ... 26th days in the solar period; $1'', 2'', 3'', \ldots\ldots 29'', 30''$ represent those corresponding to the days of the lunar synodical action, and $1''', 2''', \ldots\ldots 27'''$ those for the lunar tropical action. If we neglect the variations due to other causes, the mean horizontal force for each day, commencing all the periods with the 1st January 1844, may be represented as follows:—

Number of solar period.	1st day.	2nd day.		26th day.
1.	$1'+1''+1'''$	$2'+2''+2'''$	.....	$26'+26''+26'''$
2.	$1'+27''+27'''$	$2'+28''+0'''\cdot7$	.....	$26'+22''\cdot5+24'''\cdot7$
⋮	⋮	⋮		
14.	$1'+14''\cdot5+11'''\cdot4$	$2'+15''\cdot5+12'''\cdot4$	.....	$26'+10''+9'''\cdot1$
15.	$1'+11''+10'''\cdot1$	$2'+12''+11'''\cdot1$	.....	$26'+6''\cdot5+7'''\cdot8$
16.	$1'+7''\cdot5+8'''\cdot8$	$2'+8''\cdot5+9'''\cdot8$	.....	$26'+3''+6'''\cdot5$
17.	$1'+4''+7'''\cdot5$	$2'+5''+8'''\cdot5$	.....	$26'+29''\cdot5+5'''\cdot2$
⋮	⋮	⋮		
20.	$1'+24''+3'''\cdot6$	$2'+25''+4'''\cdot6$	.....	$26'+19''\cdot5+1'''\cdot3$
21.	$1'+20''\cdot5+2'''\cdot3$	$2'+21''\cdot5+3'''\cdot3$	.....	$26'+16''+0'''$

If now we take the sums for 17 periods of the 2nd term in each day, we may represent it in each case by

$$2\Sigma^{1}_{29\cdot5}L_{S'}=C,$$

twice the sum of the lunar synodical variation as deduced from 17 successive means at intervals of $3\frac{1}{2}$ days. In the same way the sums for 21 periods of the 3rd term in each day gives

$$\Sigma^{1}_{27\cdot3}\mathrm{L}_{\mathrm{T}}=\mathrm{C}',$$

the sum of the lunar tropical variations derived from 21 successive means at intervals of 1·3 day. If we employ, as in the following investigation, instead of the daily mean horizontal force the variations of these values from their mean, the constants C, C′ will become equal to zero. On taking then the means of the three terms for each day in 14 periods, we obtain

$$\begin{array}{lll}
\text{1st day} \quad . \ . \ . \ . \ . & 1'-\dfrac{11''+8''+4''}{14}-\dfrac{10'''+9'''+8'''+6'''+5'''+4'''+2'''}{14}, \\
\text{2nd day} \quad . \ . \ . \ . & 2'-\dfrac{12''+9''+5''}{14}-\dfrac{11'''+10'''+9'''+7'''+6'''+5'''+3'''}{14}, \\
\quad\vdots & \quad\vdots \qquad\qquad\qquad \vdots \\
\text{26th day} \quad . \ . \ . \ . & 26'-\dfrac{6''+3''+29''}{14}-\dfrac{8'''+7'''+5'''+4'''+3'''+1'''+0'''}{14}.
\end{array}$$

The *corrections* of the means for the 1st, 2nd, ... 26th days of the solar rotation derived from 14 periods are the quantities given in the 2nd and 3rd terms, with the signs changed.

In a similar manner the *corrections* of the lunar synodical and tropical variations derived from 12 and 13 periods respectively on account of the solar action uneliminated are for the lunar synodical period—

$$\begin{array}{ll}
\text{1st day} \quad . \ . \ . & +\dfrac{17'+21'+24'}{12}, \\
\quad\vdots & \qquad\vdots
\end{array}$$

and for the lunar tropical period—

$$\begin{array}{ll}
\text{1st day} \quad . \ . \ . & +\dfrac{18'+19'+20'+22'+23'+24'+26'}{13}, \\
\text{2nd day} \quad . \ . \ . & +\dfrac{19'+20'+21'+23'+24'+25'+1'}{13}, \\
\quad\vdots & \qquad\vdots
\end{array}$$

The preceding expressions represent the corrections when all the periods are supposed to commence with the same day; this, however, was not the case in the following calculations:—

For 1844, the solar period commences . . . . 1 January.
,, ,, the lunar synodical period commences . 5 ,, (full moon).
,, ,, the lunar tropical period commences . 3 ,, (moon furthest north).
For 1845, the solar period commences . . . . 30 December, 1844.
,, ,, the lunar synodical period commences . 24 ,, ,,
,, ,, the lunar tropical period commences . 23 ,, ,,

Hence, in 1844, 4″ has to be subtracted from the lunar synodical and 2‴ from the lunar tropical corrections of the solar period, while in the corrections of the former for the latter 4′ and 2′ respectively must be added. In 1845 the corresponding changes are +6″ and +7‴ in the first cases, and −6′ and −7′ in the last.

Tables I., II., and III. contain the mean variations for each of the three periods in the years 1844 and 1845 as derived from the means of 24 hourly observations in each *civil day*, together with the corrections obtained by the preceding expressions and the corrected means. It should be remarked that the quantities represented by 1′, 2′, ... 1″, 2″, ... 1‴, 2‴, ... have each been supposed unaffected by the actions of other periods; in seeking these corrections, however, the uncorrected means as derived from 14, 12, and 13 of the respective periods were employed. Any error due to this cause might have been avoided by a repetition of the corrections; the error, however, was found to be negligible in this investigation.

If we could assume not only that the variations found are those produced by the sun and moon in each period of their respective rotations or revolutions during twelve months, but also that there are no other causes of variation, we might then construct the observed results by the addition of the three variations due to the positions of a given solar meridian and of the moon relatively to the earth and sun on each day of the year. All notice, however, has been omitted of other regular or irregular causes of variation; and we have only to look at the projections of the observed means to see that great changes of the mean horizontal force occur within the space of one or two days, at intervals which cannot be connected with any continuous law. Frequent disturbances appear, especially in the means for the year 1845 (see Plate 38). It might be allowable, then, to omit these means in the investigation, or to employ interpolated quantities in their stead. It is difficult, however, to fix on the limit beyond which means should be excluded, without giving some grounds for the idea that the results obtained might not have been the same had all the observations been included. I have thought it best under these circumstances to employ *all* the observations in obtaining the variations given in Tables I., II., and III., and to make no attempt to "improve" the appearance of the results by any artifice. The year 1844 was one of minimum magnetic disturbance, and on this account the better fitted to show any law which is independent of these apparently irregular variations; I shall for this reason consider the results for that year first.

Having entered the variations belonging to the solar period in columns corresponding to each day of the year, the first quantity (column 5, Table I.) appeared opposite January 1, January 27, February 22, and so on, repeated 14 times; the quantities in column 5 of Table II. were placed in the next column, so that the first was opposite January 5, February 4 . . . . . (days of full moon), the remaining quantities following in order for each synodical revolution. Similarly the first variation (column 5 of Table III.) was entered opposite January 3, 30, February 27 . . . . (days for which the moon's north declination was greatest), the other variations following in their order. The sums of the three quantities were then taken for each day of the year.

Table I.—Variations of Daily Mean Horizontal Force for the Solar (26-day) period in millionths of the whole Horizontal Force.

Solar Day.	1844.				1845.			
	Observed Solar.	Corrections for Lunar		Corrected Solar.	Observed Solar.	Corrections for Lunar		Corrected Solar.
		Synodical.	Tropical.			Synodical.	Tropical.	
1.	+146	−44	+35	+137	+ 49	+ 7	+21	+ 77
2.	+157	−36	+23	+144	−376	−10	+16	−370
3.	+105	−28	+13	+ 90	−111	+13	−16	−114
4.	+172	−16	− 8	+148	− 28	+11	−10	− 27
5.	+ 66	−13	−16	+ 37	− 12	−13	− 4	− 29
6.	+138	− 1	−19	+118	+ 89	+ 6	+11	+106
7.	− 23	+ 8	−17	− 32	+109	+ 6	− 7	+108
8.	+ 89	+23	−11	+101	+ 70	−31	−19	+ 20
9.	−128	+29	− 2	−101	+149	−12	−18	+119
10.	−105	+32	+ 9	− 64	−281	+ 3	+ 1	−277
11.	−214	+38	+11	−165	−307	− 8	− 7	−322
12.	−324	+41	+12	−271	−194	− 8	+20	−182
13.	−318	+46	+ 6	−266	−157	+15	+17	−125
14.	−259	+46	+ 4	−209	− 93	+10	+26	− 57
15.	−313	+45	−14	−282	− 47	−21	+25	− 43
16.	−248	+46	−17	−219	+ 23	+ 6	+22	+ 51
17.	−110	+44	−26	− 92	+113	+17	+10	+140
18.	− 95	+35	−35	− 95	+ 85	− 3	+13	+100
19.	+ 8	+21	−43	− 4	+167	− 2	− 4	+161
20.	+ 62	+13	−38	+ 37	+269	+ 4	−12	+261
21.	+ 30	+ 2	−23	+ 9	+214	− 7	−22	+185
22.	+197	− 8	+ 2	+191	+ 6	− 9	− 9	− 12
23.	+307	−22	+18	+303	+ 65	+ 3	−26	+ 42
24.	+254	−26	+33	+261	+154	−10	−23	+121
25.	+267	−29	+31	+289	+ 49	−14	−20	+ 15
26.	+145	−42	+35	+138	+ 15	+13	−11	+ 17

Note.—The observed quantities (Tables I., II., & III.) are deduced from the means for each civil day given in Table xxii., Makerstoun Observations, Edinb. Trans. vol. xviii. p. 355, and Table xvii. vol. xix. pt. 2, p. 11, the means being corrected for secular change at the rate of −0·73 *per diem* for 1844, and of −0·25 for 1845. The order of corrections for the different Tables was as follows:—In 1844, 1st, the lunar tropical variations were corrected for the solar variations, the means of the variations for each three solar days being taken as corresponding to the middle day before obtaining the correction; 2nd, the solar variations were corrected for the lunar tropical (means of three taken); 3rd, the solar were corrected for the lunar synodical; 4th, the lunar synodical were corrected for the solar. In 1845, the 1st and 2nd as in 1844, the 3rd of 1844 was last in 1845.

Table II.—Variations of Daily Mean Horizontal Force for the Lunar Synodical Period (29·5 days), commencing at full moon, in millionths of the whole Horizontal Force.

Day.	1844.			1845.		
	Observed Lunar.	Corrections for Solar.	Corrected Lunar.	Observed Lunar.	Corrections for Solar.	Corrected Lunar.
1.	−208	+37	−171	+52	+1	+53
2.	−169	+35	−134	+42	+1	+43
3.	−305	+45	−260	−7	+14	+7
4.	−221	+37	−184	−45	+17	−28
5.	−341	+41	−300	−99	+20	−79
6.	−138	+21	−117	+26	+26	+52
7.	−56	+23	−33	−259	+25	−234
8.	−21	+13	−8	−161	+21	−140
9.	−40	0	−40	+60	+22	+82
10.	+111	+7	+118	+109	+14	+123
11.	+185	−28	+157	−107	+5	−102
12.	+151	−18	+133	+122	−6	+116
13.	+265	−34	+231	+162	−8	+154
14.	+209	−38	+171	+148	−5	+143
15.	+259	−49	+210	+2	−5	−3
16.	+266	−30	+236	+108	+6	+114
17.	+145	−45	+100	−67	+1	−66
18.	+205	−41	+164	−105	−9	−114
19.	+179	−27	+152	+59	−21	+38
20.	+267	−25	+242	+102	−19	+83
21.	+231	−8	+223	−123	−19	−142
22.	+148	+10	+158	−41	−18	−59
23.	+165	+14	+179	−259	−21	−280
24.	+169	+32	+201	−57	−11	−68
25.	−106	+38	−68	+83	−9	+74
26.	−274	+38	−236	+50	−12	+39
27.	−211	+37	−174	+146	−12	+134
28.	−333	+35	−298	−40	+1	−39
29.	−222	+45	−177	+145	+14	+159
30.	−313	+37	−276	−53	−7	−60

Note.—When there were only 29 days in a lunation, −227 (the mean for the 29th and 30th days) was employed for the 30th day in 1844, and +50 in 1845. See Note to Table I.

Table III.—Variations of Daily Mean Horizontal Force for the Lunar Tropical Period (27·3 days), commencing with Moon's greatest North Declination, in millionths of the whole Horizontal Force.

Day.	1844.			1845.		
	Observed Lunar.	Corrections for Solar.	Corrected Lunar.	Observed Lunar.	Corrections for Solar.	Corrected Lunar.
1.	+179	+ 83	+262	+177	−29	+148
2.	+164	+ 92	+255	+ 57	− 1	+ 56
3.	+269	+ 95	+364	+136	+19	+155
4.	+ 88	+ 97	+185	−124	+40	− 84
5.	− 61	+ 84	+ 23	− 3	+54	+ 51
6.	−263	+ 74	−189	− 75	+62	− 13
7.	−172	+ 54	−118	−132	+59	− 73
8.	−145	+ 45	−100	−232	+62	−170
9.	− 65	+ 23	− 42	−154	+53	−101
10.	− 61	+ 9	− 52	− 99	+41	− 58
11.	− 75	− 20	− 95	−130	+13	−117
12.	+116	− 39	+ 77	+ 29	− 1	+ 28
13.	+ 67	− 68	− 1	− 47	−14	− 61
14.	+151	− 86	+ 65	− 50	− 9	− 59
15.	+130	−106	+ 24	+129	−10	+119
16.	+190	−114	+ 76	+163	− 7	+156
17.	+202	−120	+ 82	+166	−22	+144
18.	+129	−116	+ 13	+ 5	−20	− 15
19.	+ 73	−103	− 30	−328	−23	−351
20.	+ 19	− 81	− 62	− 38	−20	− 58
21.	+ 13	− 55	− 42	− 1	−32	− 33
22.	−169	− 25	−194	+ 48	−36	+ 12
23.	−120	+ 7	−113	+ 80	−38	+ 42
24.	−103	+ 36	− 67	+ 24	−37	− 13
25.	−284	+ 62	−222	+ 67	−50	+ 17
26.	−134	+ 75	− 59	+161	−46	+115
27.	−125	+ 83	− 42	+182	−29	+153

Note.—When there was a 28th day in the period, +110 and +150 (the means for the 27th and 1st days) were employed for that day in 1844 and 1845 respectively. See Note to Table I.

It will be remembered that these variations are those about the means in each case; it has been considered a sufficiently near approximation to the mean horizontal intensity for each day, and for each of these periods, to take the means for four weeks, two weeks preceding and two weeks following each day. The observed means for each *civil* day having then been projected and connected with black lines, the curve of four-weekly means was formed by a dark dotted line (see Plate 38); from this line the sums of the three variations were set off *plus* or *minus*, and connected by red lines drawn from point to point.

It requires only a glance at these projections to see with how much fidelity the calculated represents the observed curve, in spite of the effects of the larger irregular variations on the means for each period, and on the appearance of the observed curves for the periods in which they occur.

The conclusions drawn are as follows:—

1st. The increase of amplitude of the oscillations which appears in February and March, and in September to November, 1844, is explained by the occurrence, near the same time, of the maximum actions of the sun and moon. In order to show this fact more distinctly, the separate actions of each body are projected above the oscillation for February 1844 (Plate 38).

2nd. The diminution and apparent disappearance of the oscillations in June and July, which seemed so inexplicable when only one cause of variation was supposed to exist, are explained by the opposing actions of the two causes, the maximum of the one occurring at the same time as the minimum of the other. The independent actions of each body are shown in the projections below the movement for June (Plate 38).

3rd. The variation of the time of single oscillations is explained in a similar manner by the combinations of the different variations.

4th. Since the agreement between the observed and calculated results is so considerable, we are entitled to conclude that during a period of twelve months the solar and lunar actions remained nearly constant for the same positions of these bodies relatively to the earth and to each other.

Had it been sought merely to establish the fact that the variations of the daily mean horizontal force of the earth's magnetism may be represented very nearly in years of small magnetic irregularity by the computed variations due to three causes having periods of 26, 27·3, and 29·5 days, the investigation might have stopped here. It seemed to me, however, desirable to examine to what extent the same process would succeed in a year for which the movements appeared more irregular. The variations for 1845 were therefore calculated from the means in the last columns of Tables I., II., and III., in the same way as has been explained for 1844, commencing January 1, 1845, with the 3rd day of the solar, the 9th of the lunar synodical, and the 10th of the lunar tropical period.

The sums of variations for each day having been obtained, they were set off from the curve of four-weekly means as before (see Plate 38).

We perceive at once that the *observed* variations of daily mean horizontal force did not show the same regularity in the oscillations as in 1844; considerable disturbances seem to have occurred at irregular intervals destroying the symmetry of the movements. It could scarcely be expected that any calculation in which the same quantities are employed successively from 12 to 14 times during the year could give an approximation to the observed movements throughout the period. I believe, however, it will be seen that the resemblance of the calculated and observed results is very considerable; and although at first sight the agreement of the red and black oscillations may not appear so satisfactory as in 1844, yet a more minute examination will show the frequent coincidences, which are all the more extraordinary that the irregularities throughout the year appear so marked. The variations due to each period in 1845 are projected below the movements for June. The maximum solar action occurs about 4 or 5 days earlier in 1845 than in 1844, the supposed duration of the period being 26 days; this may be due to a change of the solar meridian producing the maximum, or to the action of superposed irregular disturbances (which, there can be no doubt, have an effect on the mean result), or to the true period being slightly less than 26 days*.

The lunar action has also undergone a change, since a maximum occurs both near new and near full moon; this result is also affected by the irregular variations. I shall notice immediately the fact that the moon's action in producing the magnetic variations appears to depend upon the sun. There is in 1845, as in 1844, a maximum both when the moon is near her greatest northerly and her greatest southerly declination.

It is not my object here to enter into the differences of the results for each period as derived from each of the two years' observations, or to seek whether these differences may not be due to the greater number of irregular movements which occurred in 1845; the consideration of these questions must include the study of a longer series of observations; yet I may add that it seems to me the least probable supposition that the meridian of maximum solar action which remained constant throughout 1844 had changed in 1845.

The conclusion deduced from the curves for 1844, of the constancy of the solar and lunar actions during twelve months, is confirmed generally, I think, even with the superposed sudden movements of 1845.

Magnetic Pulsations.

The view generally entertained of the source of the great magnetic disturbances is, that they are produced by some action of the sun; this conclusion is founded on the diurnal law of frequency and magnitude which these movements follow. The diurnal law, however, appears modified by conditions of latitude; the maximum disturbance which occurs near midnight in high latitudes happens near noon within the tropics. I have shown, however, that the great changes of *daily mean* horizontal intensity are experienced similarly at all the stations considered between 56° North and 42° South latitude where observations had been made*. When a great diminution of mean daily force occurs at one station, a similar and nearly equal diminution occurs at the others. If this diminution be due to a solar action only, such as, it has been supposed, might result from some considerable movements in the sun's envelopes, and if the moon has no part in the production of the resulting changes of terrestrial magnetism, the means obtained for the solar period will be affected by true solar actions, while those for the lunar periods would be affected by changes in the production of which the moon took no part. Were this certain there would be reasons for omitting great and sudden departures from the mean in the discussions for the moon's periods, which do not exist in those for the sun. As the mean variations due to the moon's action appear so considerable when compared with those due to the sun, it does not seem at all certain that the great magnetic disturbances are wholly solar. An effort is here made to examine this subject.

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* See Proceedings of the Royal Society, vol. xx. p. 421.

We have seen that when one side of the sun is presented to the earth, the magnetic force of the latter is greater than when the other side is turned towards us; we may even say that the intensity is greatest for a given solar meridian; this, however, may be simply an integral effect resulting from the actions due to all the meridians. But can we suppose when a great and sudden increase or diminution of the earth's magnetic force occurs that this is produced by some change occurring on a particular solar meridian? This does not seem at all improbable. It could scarcely, however, be supposed that the effect produced on the earth's magnetism could be due to the given solar meridian being presented to (that is, in the same plane with) the earth, unless we admit the idea that these solar magnetic actions are propagated only in certain definite directions, or that the earth has some action in the production of the solar change when the given meridian is presented to it.

In order to examine the facts, all the cases were noted during the years 1844 and 1845 in which the *daily mean* horizontal force diminished one thousandth of its whole value *within* an interval of three days; they were found to be twenty-eight in number. If we call the solar meridian presented to us on the 1st January, 1844, the zero meridian (0), and consider the time of rotation to be 26 days, and that there are 26 meridians, we find that the solar meridians presented to us when these great movements occurred may be arranged in a few groups, as in the following Table.

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* Trans. Roy. Soc. Edinb. vol. xxii. p. 545.

Table IV.—Cases in which the Earth's Magnetic Force diminished one thousandth of its whole value or more in 1844 and 1845.

No. of case.	Dates of beginning and ending.	Change of force in hundred thousandths.	Solar meridians.		
			5 to 10.	11 to 14.	−3 to +1 and others.
1.	1844. Mar. 28 to Mar. 30	−360	+8 to +10		
2.	Apr. 25 „ Apr. 26	104	....	+11 to +12	
3.	May 21 „ May 23	107	....	+11 „ +12	
4.	July 8 „ July 9	116	+7 to + 8		
5.	Aug. 1 „ Aug. 2	175	+5 „ + 6		
6.	Aug. 9 „ Aug. 10	135	....	+13 „ +14	
7.	Sept. 24 „ Sept. 27	115	+7 to +10		
8.	Sept. 30 „ Oct. 1	104	....	+13 „ +14	
9.	Oct. 19 „ Oct. 21	268	+6 to + 8		
10.	Nov. 19 „ Nov. 21	130	....	+13 „ +14	
11.	Dec. 27 „ Dec. 30	165	....	....	−3 to 0
12.	1845. Jan. 8 „ Jan. 10	210	+9 to +11		
13.	Jan. 18 „ Jan. 20	163	....	....	(−6 „ −4)
14.	Feb. 20 „ Feb. 21	118	....	....	0 „ +1
15.	Apr. 12 „ Apr. 14	350	....	....	−1 „ +1
16.	June 10 „ June 12	110	+6 to + 8		
17.	July 24 „ July 25	154	....	....	−2 „ −1
18.	July 31 „ Aug. 3	102	+6 to + 9		
19.	Aug. 26 „ Aug. 27	101	+5 „ + 6		
20.	Aug. 29 „ Aug. 30	159	+8 „ + 9		
21.	Sept. 24 „ Sept. 25	153	+8 „ + 9		
22.	Oct. 8 „ Oct. 10	126	....	....	(−4 „ −2)
23.	Oct. 20 „ Oct. 21	118	+8 to + 9		
24.	Oct. 30 „ Nov. 1	100	....	....	(−8 „ −6)
25.	Nov. 15 „ Nov. 18	100	+8 to +10		
26.	Nov. 27 „ Nov. 29	110	....	....	(−6 „ −4)
27.	Dec. 3 „ Dec. 4	291	....	....	0 „ +1
28.	Dec. 11 „ Dec. 13	122	+8 to +10		

An examination of this Table will show that nearly half of the great changes began when the 8th meridian after the zero had passed, while five began near the 12th after, and five near the zero itself. The two greatest changes of magnetic force in 1844 happened near the + 8 meridian, and the two greatest in 1845 at the 0 meridian*.

* Kreil, who obtained so many interesting results, has noticed the fact that great disturbances occurred frequently on the same, or nearly the same, day of successive years. "Thus the greatest disturbances which took place in the year 1836 were on the 22nd and 23rd April and on the 18th October, and both these were repeated on the same days in 1837." In 1838 several disturbances occurred within a few days of the same dates of 1837, a list of which he gives. He also draws attention to the fact of "the symmetrical arrangement of these disturbances in the same year, many of them being nearly six months apart" (Phil. Mag. 1840, vol. xvi. p. 246). It has been pointed out that 14 solar rotations are performed in 364 days, or within one day of the year; there are also 7 rotations in six months. The recurrence exactly after twelve or six months does not appear for the years 1844 and 1845, but of the five *greatest* changes of daily mean horizontal force (Cases Nos. 1, 9, 12, 15, and 27) the first two were at an interval of 8 periods of 26 days, the second and third at an interval of 3 periods of 26 days, and the fourth and fifth at an interval of 9 solar rotations. As, however, the disturbances obey also an annual law with the maxima near the equinoxes (as I first pointed out in 1847), the probability is the greatest of disturbances recurring at the end of 7 rotations (six months), or 12 rotations (one year), near the equinoxes.

If any doubt existed as to the possibility of these being mere accidental coincidences, it would be removed, I think, by a consideration of the marked succession occurring between July 31st and December 11th, 1845. It will be observed that though considerable magnetic changes occur successively near the same solar meridian, yet that they do not always occur in successive rotations; thus a great disturbance commenced at +8, March 28, 1844, but no other above the limit appears till July 8th at the same solar meridian. For this reason the succession mentioned merits particular consideration. If we neglect the two cases of July 31 and August 26, which commence at +6 and +5 respectively, we have five cases of successive solar rotations in which the diminutions of intensity began on the +8 day*. This exact recurrence at the end of 26 days of the marked diminution of force proves, it seems to me, *that the actions are all due to the sun*, whose time of rotation must be very nearly 26 days.

An examination of the projected means will show that the sudden diminutions of terrestrial magnetic force are in nearly every case preceded by a sudden increase. It seems extremely difficult to explain these regular pulsations, which are felt all over the earth†, by any theory of distribution of magnetism on the solar surface, or by any variations of temperature on the earth, or to understand why the sudden increase should have ended and the rapid diminution of magnetic force should have begun exactly when the solar meridian +8 arrived at the same position *relatively to the earth*, without admitting that the earth itself had some part in their production—a part which might be due, however, merely to her passage through some ray-like, electrical emanation from the sun.

Lunar Disturbing Action.

Has the moon, then, no part in the production of these disturbances? Since the earth's magnetic force varies during the solar rotation, we may suppose that the moon's magnetic intensity varies from the same cause; but we can scarcely conclude that a change of the moon's intensity with a period of 26 days could produce the comparatively large results found for periods of 29·5 and 27·3 days. I have shown elsewhere that the moon's action on the *diurnal* variation of the *easterly* horizontal force near the equator depends on the sun's position. The moon when on a given terrestrial meridian draws the north end of a needle to the east when the sun is furthest north, and to the west when he is furthest south; the lunar action on the needle is much the greatest during the day (whether the moon be above the horizon or below it), and the lunar action is inverted at sunrise*. We can then only suppose that the moon may attract (or repel) the electric medium through which the solar disturbances are propagated.

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* See Plate 38, where the diminutions in the latter half of 1845 at the +8 meridian are indicated by thick lines. It will be seen that considerable diminutions of intensity occurred near the +8 meridian from the beginning of 1844 to the end of 1845, but that marked diminutions near the zero meridian began in the last days of 1844.

† See plate xxvii. Trans. Roy. Soc. Edinb. vol. xxii., where the variations are given for Makerstoun, Trevandrum, Singapore, and Hobarton. It should be remarked that the projections in that plate are for the Göttingen *astronomical* day, whereas in the Plate illustrating this paper they are for the Makerstoun *civil* day.

If the recurrence of great terrestrial magnetic changes at given solar meridians holds for every rotation of the sun, it is obvious that they should happen equally for all the different positions of the moon; this constant recurrence, however, does not exist, and it is possible that this may be due to the particular positions of the moon, or that the position of the moon may determine the action on the earth. In order to examine this, the same 28 cases were arranged relatively to the moon's positions with reference to the sun and to the equator.

It was found that on the whole more of the large disturbances occurred when the differences of the sun's and moon's longitudes were near + or −90°; but the excess in the quadrants having these differences for the middle points is not sufficiently great alone to give any considerable weight to the conclusion that the disturbances happen preferably near these positions. It may be remarked, however, that the four greatest disturbances during the two years, namely those on March 28 and October 19, 1844, and April 12 and December 3, 1845 (Nos. 1, 9, 15, and 27), in which the mean daily horizontal force diminished from 0·0027 to 0·0036 of its whole value, occurred when the moon was nearly in her first quarter.

On the other hand, when the cases are examined with regard to the moon's position in declination, there can be no doubt that there was one position of the moon for which the disturbances were most frequent, as may be seen in the following Table (p. 402).

The diminution of magnetic force began in eleven cases when the moon was within two days of the greatest northerly position; there were three cases within three days of the greatest southerly position (see Table V.). When the cases are arranged in groups having nearly the same declination, we find

15 cases, mean declination beginning 18°·2 N., ending 14°·0 N.
5 ,, ,, ,, 12·4 N., ,, 16·4 N.
3 ,, ,, ,, 15·3 S., ,, 8·3 S.
3 ,, ,, ,, 12·0 S., ,, 17·0 S.
2 ,, ,, ,, 2·5 S., ,, 7·0 N.

There were therefore 20 cases for which the diminution of intensity began when the moon was on the average 16°·7 N., and which ended when she was 14°·4 N. There were only 6 cases for the moon wholly south of the equator. The majority of cases began immediately *after* the moon had attained her greatest north declination (21° nearly).

Since the moon took nearly the same time to pass from the equator to 15° N. as from 15° N. to the greatest northerly position, I have sought for which of these two intervals the cases were most frequent. It appears that of the 20 cases which occurred with the moon north of the equator, 13 happened when her mean position (from beginning to ending of the diminution of intensity) was 18°·7, and 7 when she was 10°·2, so that

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* Trevandrum Observations, vol. i. pp. 117, 121, 123.

Table V.—Moon's Positions in Declination and in Latitude in each case.

No. of case.	Days from Moon furthest north. Diminution commencing				Moon's mean latitude.			
					Greater than 3°·0.		Less than 3°·0.	
	−9 to +11.	−2 to +2.	+3 to +5.	Other days.	South.	North.	South.	North.
	d	d	d	d				
1.	......	......	+ 3	......	−3°·0 to −4°·5			
2.	......	......	+ 4	......	−3·8 „ −4·5			
3.	......	+ 2	......	......	−2·8 „ −4·4			
4.	......	......	......	− 4	....	+3°·8 to +2°·9		
5.	......	......	......	− 8	....	+5·1 „ +4·9		
6.	......	0	......	......	....	....	−1°·0 to −2°·0	
7.	......	......	......	− 8	....	+5·0 to +4·0		
8.	......	− 2	......	......	....	....	....	+1°·3 to +0°·3
9.	......	......	......	− 9	....	+4·5 to +5·2		
10.	......	......	......	− 7	....	+4·9 „ +3·7		
11.	......	......	+ 4	......	−4·5 to −5·1			
12.	−10	......	......	......	....	+3·7 „ +5·0		
13.	......	− 1	......	......	....	....	+0·1 to −1·9	
14.	......	......	+ 5	......	−4·7 to −5·0			
15.	......	+ 1	......	......	−2·6 „ −4·2			
16.	......	......	+ 5	......	−5·2 „ −5·0			
17.	......	......	......	− 5	....	....	....	+3·4 „ +2·4
18.	......	+ 2	......	......	−3·5 to −4·9			
19.	......	+ 1	......	......	−2·6 „ −3·5			
20.	......	......	+ 4	......	−4·6 „ −4·9			
21.	......	+ 2	......	......	−4·2 „ −4·7			
22.	−10	......	......	......	....	+4·4 to +5·2		
23.	......	+ 1	......	......	−3·3 to −4·1			
24.	+11	......	......	......	....	....	−1·5 to +1·1	
25.	......	0	......	......	−2·0 to −4·5			
26.	+12	......	......	......	....	....	....	−0·7 „ +1·8
27.	−10	......	......	......	....	+5·2 to +5·2		
28.	......	− 2	......	......	....	....	−0·6 to −2·7	

the more northerly cases were the more frequent. In the same way it is found that of the 6 cases for which the moon was south of the equator, in 4 the mean declination was more than 15° (=15°·6) and in 2 less (=10°·8). There were thus only 2 cases remaining for which the mean declination of the moon was within the limits 10°·2 N. and 10°·8 S., a space covering half the moon's whole path.

It would appear, then, that the exact recurrence of the greater diminutions of terrestrial magnetic force for certain days happens only in the solar period, but that their frequency depends on the position of the moon relatively to the equator. It may also be remarked for the cases Nos. 18, 19, 20, 21, 23, 25, and 28, for which the disturbance commenced near the solar meridian +8, the moon was within two days of her greatest northerly declination (except one case, for which her mean declination was 15° N.).

It has been supposed that this apparent action of the moon is due to her position relatively to the *equator*; but as the nodical period differs only 0·11 day from the tropical, it is possible that it is her position relatively to the *ecliptic* which is in question. I have in consequence examined the cases with regard to the moon's latitude, with the following results (see Table V.). Noting that the greatest latitudes are between 5°·0 and 5°·3, we find

13 cases, mean latitude beginning 3°·6 S., ending 4°·6 S.
8 „ „ „ 4·6 N., „ 4·5 N.
1 case „ „ 3·4 N., „ 2·4 N.
6 cases beginning and ending within the limits 3·0 S. and 3°·0 N.

There were 21 cases for each of which the moon's mean latitude was greater than 3° S. or than 3°·3 N.; 1 case for which the mean latitude was 2°·9 N.; and 6 cases for which the mean latitudes were between 1°·7 S. and 0°·8 N. The relative amounts of the diminutions of magnetic force are projected on curves supposed to represent the moon's path in declination (fig. A) and in latitude (fig. B, Plate 38).

It will be seen from these two figures that 13 cases occurred for the moon when passing from the greatest northerly declination towards the equator, while for the passage below the ecliptic there were 16 cases. From near the greatest *southerly* latitude (fig. B) to near the greatest northerly latitude (embracing 11 days of the whole period) there were only 2 cases. The proportion of cases for the two portions of the moon's path was as 26 : 2, whereas the ratio should have been as 16 : 12 had the chances of disturbance been equal for all parts of the moon's orbit.

There is no doubt, then, that in 1844 and 1845 the greater disturbances of mean magnetic force occurred most rarely when the moon was near the equator or ecliptic; but it is not possible to determine from two years' observation whether the moon's action depends on her position relatively to the one or the other plane only, or to both. If *the thing acted on*, whatever that may be, *retains the same position* relatively to these planes, the discussion of 5 or 6 years' observations will show to which plane these results should be referred.

The preceding investigation was limited to cases for which the diminution of daily mean horizontal force within three days was not less than one thousandth of its whole value; the change of daily mean horizontal force from day to day (without regard to sign or limit) has also been sought for the solar and each of the lunar periods. The results confirm the conclusions already derived from the greater negative movements, as to the solar meridians and moon's latitudes for which the disturbance is a maximum. I shall defer, however, the consideration of this part of the investigation till a longer series of observations has been discussed.

XVI. *On the Expansion of Sea-water by Heat.* *By* T. E. THORPE, *Ph.D.*, *and* A. W. RÜCKER, *M.A.* (*Fellow of Brasenose College, Oxford*), *Professors of Chemistry and Physics in the Yorkshire College of Science.* *Communicated by* W. B. CARPENTER, *M.D., LL.D., F.R.S.*

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THE extensive contributions which have recently been made to the physical history of the ocean have shown the desirability of exact knowledge of the relations of sea-water to heat. We have accordingly thought it worth while to make observations in order to determine the law of the thermal expansion of sea-water.

Hitherto the most important attempt to solve this problem was made by the late Prof. HUBBARD, of the United States National Observatory; the results of his investigation are contained in MAURY'S 'Sailing Directions,' 1858, vol. i. p. 237.

MUNCKE, nearly 50 years ago, determined the expansion of an artificial sea-water at various temperatures between 0° and 100° C.; but our confidence in the results as applicable to natural sea-water is affected by the circumstance that the solution was prepared from data furnished by the imperfect analyses of VOGEL and BOUILLON LA-GRANGE.

The observations of DESPRETZ were confined to temperatures below 13°·27, as the main object of his inquiry was to determine the point of maximum density of sea-water. The subsequent investigations of NEUMANN and ROSSETTI were equally limited, as they were undertaken with the same view.

In accordance with our instructions, Captain CAMPBELL, of the Anchor Liner 'Europa,' kindly obtained for us a number of samples of Atlantic-Ocean water at various periods during a voyage from New York to Glasgow. The particular sample selected for observation was collected in lat. 50° 48′ N. and long. 31° 14′ W. The temperature of the surface-water was 52°·5 F. In the remarks accompanying the specimen it is stated that "the weather had been moderate and pleasant for some days previously, and up to the morning of collection; since then have had a brisk S. gale with heavy cross sea." Two series of experiments have been made with this sample.

In the first series our method of observation was precisely the same as that already employed by one of us in determining the expansion of the liquid chlorides of phosphorus*. It was essentially that already used by KOPP and PIERRE; *i. e.* the expansion was observed in thermometer-shaped vessels (so-called *dilatometers*) graduated and accurately calibrated. The dilatometers were constructed of flint glass containing 33 per cent. of oxide of lead, and the coefficients of expansion were determined for the limits of temperature between which our observations were made by observing the increase in the apparent volume of mercury. The calibration was made by a method substantially the same as that employed by KOPP—that is, by determining the weights of mercury contained in the various parts of the graduated stems. In several particulars, however, the method actually adopted possessed some points of advantage over that upon which it was based, both in improved modes of keeping the temperature of the bath constant and in withdrawing the mercury, and also in the plan adopted of weighing the mercury withdrawn so as to avoid removing the instrument from the bath. The thermometer used was one of a set made by CASELLA; 1° on each instrument had a length of about 9 millims. They were previously compared with Kew Standards belonging to Sir W. THOMSON. Frequent determinations were made of the zero-point of the thermometer during the progress of the observations; indeed the alteration in the fixed point had been noted sufficiently often over a period of nearly six years to make it possible to represent it by means of an equation like that obtained under similar conditions by Prof. W. H. MILLER ("Determination of Standard Pound," Phil. Trans. for 1855). The bath in which the instruments were immersed contained from thirty to forty litres of water, which was agitated by a stirrer worked by a small hydraulic engine. Direct experiments have shown that the temperature of the whole mass was thus made sensibly uniform.

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* Proc. Roy. Soc. vol. xxiii. p. 364.

The bath was heated by steam driven in from a small metallic boiler. When the temperature at which an observation was to be made was nearly attained, the delivery of the steam was regulated so as to maintain the temperature as nearly as possible constant; and at least six observations were made with a very slowly rising and an equal number with a very slowly falling thermometer. The readings were obtained by the aid of a telescope furnished with a micrometer-eyepiece, and the result given in each case is the mean of at least six observations.

As we desired to make our observations on the sea-water in its natural condition, it was considered unnecessary to attempt to extend them over a wide range of temperature. It was found that the water might be heated to about 50° C. before the air in solution made its appearance, provided that the dilatometer was kept perfectly still; but from the unavoidable vibration produced by the action of the stirrers in the bath, minute bubbles were formed at four or five degrees below this point. Accordingly the observations have not been extended beyond 40°. For the purpose of reducing specific-gravity observations this limit is amply sufficient, since sea-water never attains so high a temperature even in shallow places within the tropics.

The specific gravity of the sea-water at 0° C., compared with distilled water at the same temperature, was found, by the bottle, to be 1·02867.

The results of the first series of observations are contained in Table I.

TABLE I.

Dilatometer B. Thermometer A.

Temp. C.	Obs. vol.	Calc. vol.	Diff.
0°·00	2828·56	2828·54	−0·02
3·34	2829·03	2829·03	0·00
6·54	2829·83	2829·84	+0·01
9·58	2830·89	2830·91	+0·02
12·75	2832·35	2832·30	−0·05
15·94	2833·95	2833·98	+0·03
19·15	2835·91	2835·93	+0·02
22·32	2838·00	2838·09	+0·09
25·45	2840·55	2840·44	−0·11
28·88	2843·27	2843·24	−0·03
32·08	2846·01	2846·05	+0·04
35·02	2848·78	2848·77	−0·01

These results may be represented with sufficient accuracy by a formula of the form

$$V=K+Lt+Mt^2+Nt^3.$$

The values of the constants K, L, M, and N were found by substituting successively for V and t the 12 corresponding values given in the Table as deduced from the experiments, and the expressions so obtained were then added together in consecutive groups of three, so as to form 4 equations of condition by the solution of which the 4 unknown quantities were determined.

The values of K, L, M, and N were thus found to be—

$$K=2828{\cdot}540,$$
$$L=\quad 0{\cdot}091311,$$
$$M=\quad 0{\cdot}0171712,$$
$$N=-\ 0{\cdot}00009373.$$

The third column in the foregoing Table gives the volumes, calculated by the aid of these values, which correspond to the observed temperatures contained in the first column; and the fourth column shows the differences between the observed and calculated results.

Dividing each coefficient by K, and correcting for the expansion of the glass (0·0000254 for 1° C.), we obtain the following formula, as representing the expansion between 0° and 36° of sea-water of sp. gr. 1·02867 at 0°, the volume at 0° being 1.

$$V=1+{\cdot}000057682\,t+{\cdot}0000060715\,t^2$$
$$-{\cdot}000000032983\,t^3.$$

The variations in the specific gravity of oceanic waters are, comparatively speaking, very small; according to the observations of Mr. J. Y. BUCHANAN, the Chemist to the 'Challenger' Expedition, they lie between the extremes 1·0278 and 1·0240. Still the question suggests itself—Is the law of the thermal expansion, as deduced from the foregoing observations, strictly applicable to all oceanic waters? The importance of an answer to this question will be evident when we bear in mind that, in order to be of value in the investigation of the physical condition of the ocean, the results of the observations of the specific gravity of sea-water must be correct to one in the fourth decimal place. Of course we should have reason to expect that the variations in the rate of expansion of sea-water as it usually occurs, although doubtless appreciable, must be very small; nevertheless we thought it desirable to attempt to determine the relation between the salinity of the water, as indicated by the specific gravity, and its thermal expansion. Accordingly we constructed dilatometers of greatly increased capacity; and in order to expose a larger surface to the source of heat the bulbs were made in the form of elongated cylinders instead of being spherical, as in the case of the instrument we had hitherto employed. The new instruments were calibrated with great care, and the determination of the rates of expansion of the glass was made between the limits of temperature to which they were to be used. An additional set of thermometers was made for us by CASELLA; they are denoted in the succeeding Tables by α and β. Thermometer α was graduated for temperatures between $-9°$ and 29°; the length of 1° was 13 millims.; the range of β was from 21° to 67°, and the length of 1° was about 11 millims. Both instruments could therefore be easily read to 0°·01.

As it was desirable to obtain data to cover all possible cases of dilution and concentration in naturally occurring sea-water, we diluted quantities of our sea-water with distilled water so as to have samples of, approximately, the specific gravities 1·020 and 1·025; and we concentrated a third quantity by evaporation until its specific gravity was increased to about 1·033. We also redetermined the expansion of the original sea-water by means of the new dilatometers. Two perfectly independent series of observations were made with each solution, different dilatometers and thermometers being used in each case.

The details of the observations are exhibited in Tables II.–IX.; the first column in each gives the reduced and corrected temperatures, and the second the reduced volume (uncorrected for expansion of glass) of the liquid in the dilatometer. Formulæ expressing these results were obtained by the same method as that applied to the first set of observations as described on p. 407; and as in some of the series of experiments more than twelve observations were made, while in no case was a larger number used in deducing the formulæ, we have in the Tables marked the observations not employed for that purpose with an asterisk. The formulæ are given at the head of the Tables containing the observations to which they refer; the volumes calculated by their aid for the temperatures in the first columns are given in the third columns, the differences between the observed and calculated values being exhibited in the fourth columns. The specific gravities were taken at 0°, and are referred to distilled water of the same temperature.

Table II.

Sample A.

Determination of Specific Gravity:—

Experiment I.	1·03298
„ II.	1·03305
Mean	1·033015

Series I. Dilatometer O. Thermometer A.

$$V=6179{\cdot}487+0{\cdot}38985\,t+0{\cdot}0294072\,t^2 -0{\cdot}000075624\,t^3.$$

Temp. C.	Obs. vol.	Calc. vol.	Diff.
7·07°	6183·81	6183·69	−0·12
10·10	6186·30	6186·35	+0·05
12·90	6189·17	6189·25	+0·08
16·85	6193·97	6194·04	+0·07
19·38	6197·59	6197·54	−0·05
22·29	6201·97	6201·95	−0·02
24·99	6206·42	6206·41	−0·01
26·90	6209·75	6209·78	+0·03
30·04	6215·71	6215·69	−0·02
32·89	6221·33	6221·43	+0·10
35·74	6227·65	6227·53	−0·12
39·67	6236·49	6236·51	+0·02

Table III.

Sample A. Series II.

Dilatometer P. Thermometers α and β.

$$V=6177{\cdot}933+0{\cdot}31536\,t+0{\cdot}0335818\,t^2 -0{\cdot}000151131\,t^3.$$

Temp. C.	Obs. vol.	Calc. vol.	Diff.
0·00°	6178·02	6177·93	−0·09
1·99	6178·64	6178·69	+0·05
4·31	6179·87	6179·90	+0·03
6·34	6181·23	6181·24	+0·01
9·02	6183·39	6183·40	+0·01
12·08	6186·40	6186·38	−0·02
*15·25	6189·98	6190·02	+0·04
18·18	6193·88	6193·86	−0·02
20·86	6197·83	6197·75	−0·08
23·87	6202·44	6202·54	+0·10
*24·06 β	6202·80	6202·86	+0·06
27·91	6209·57	6209·61	+0·04
30·25	6214·03	6214·02	−0·01
32·79	6219·08	6219·05	−0·03

Table IV.

Sample B (undiluted sea-water).

Estimation of Specific Gravity:—

Experiment I.	1·02866
,, II.	1·02866
Mean . . .	1·02866

Series II. Dilatometer P. Thermometer A.

$$V = 6173{\cdot}037 + 0{\cdot}21316t + 0{\cdot}0365255t^2 - 0{\cdot}000185263t^3.$$

Temp. C.	Obs. vol.	Calc. vol.	Diff.
°4·11	6174·52	6174·52	0·00
7·07	6176·34	6176·30	−0·04
10·08	6178·67	6178·70	+0·03
12·91	6181·43	6181·45	+0·02
16·85	6186·16	6186·11	−0·05
19·38	6189·54	6189·54	0·00
22·29	6193·94	6193·88	−0·06
25·00	6198·33	6198·30	−0·03
26·90	6201·51	6201·59	+0·08
30·04	6207·40	6207·38	−0·02
32·90	6212·93	6212·99	+0·06
35·74	6218·90	6218·85	−0·05
39·67	6227·42	6227·41	−0·01

Table V.

Sample B. Series III.

Dilatometer O. Thermometers α and β.

$$V = 6192{\cdot}135 + 0{\cdot}17498t + 0{\cdot}0379567t^2 - 0{\cdot}000207014t^3.$$

Temp. C.	Obs. vol.	Calc. vol.	Diff.
°0·00	6192·13	6192·14	+0·01
1·99	6192·63	6192·63	0·00
4·30	6193·58	6193·57	−0·01
6·34	6194·71	6194·72	+0·01
9·02	6196·65	6196·65	0·00
12·08	6199·43	6199·42	−0·01
*15·25	6202·94	6202·90	−0·04
18·17	6206·54	6206·60	+0·06
20·86	6210·57	6210·42	−0·15
23·87	6215·04	6215·12	+0·08
*24·07 β	6215·40	6215·45	+0·05
27·91	6221·98	6222·08	+0·10
30·26	6226·27	6226·45	+0·18
32·78	6231·65	6231·36	−0·29

Table VI.

Sample C.

Determination of Specific Gravity:—

Experiment I.	1·02494
„ II.	1·02489
Mean . . .	1·024915

Series I. Dilatometer O. Thermometers α and β.

$$V = 6193{\cdot}603 + 0{\cdot}10714t + 0{\cdot}0381813t^2 - 0{\cdot}000191475t^3.$$

Temp. C.	Obs. vol.	Calc. vol.	Diff.
0·00°	6193·68	6193·60	−0·08
3·24	6194·29	6194·34	+0·05
6·45	6195·81	6195·83	+0·02
9·65	6198·00	6198·02	+0·02
12·77	6200·76	6200·80	+0·04
15·84	6204·18	6204·12	−0·06
18·88	6208·04	6207·95	−0·09
21·98	6212·45	6212·37	−0·08
24·98	6216·95	6217·12	+0·17
28·15 β	6222·50	6222·60	+0·10
31·13	6228·09	6228·16	+0·07
34·31	6234·67	6234·49	−0·18
*36·71	6239·64	6239·52	−0·12

Table VII.

Sample C. Series II.

Dilatometer P. Thermometer A.

$$V = 6178{\cdot}490 + 0{\cdot}09990t + 0{\cdot}0392112t^2 - 0{\cdot}000220711t^3.$$

Temp. C.	Obs. vol.	Calc. vol.	Diff.
0·00°	6178·39	6178·49	+0·10
2·95	6179·21	6179·12	−0·09
4·51	6179·73	6179·74	+0·01
7·50	6181·36	6181·35	−0·01
10·41	6183·48	6183·53	+0·05
15·00	6188·11	6188·07	−0·04
17·35	6190·95	6190·87	−0·08
20·95	6195·70	6195·76	+0·06
23·83	6200·14	6200·15	+0·01
26·60	6204·64	6204·73	+0·09
29·84	6210·51	6210·52	+0·01
32·91	6216·49	6216·38	−0·11

TABLE VIII.

Sample D.

Determination of Specific Gravity :—

Experiment I.	1·02079
,, II.	1·02072
Mean . . .	1·020755

Series I. Dilatometer P. Thermometers α and β.

$$V = 6177{\cdot}987 + 0{\cdot}02119t + 0{\cdot}0442784t^2 - 0{\cdot}000313329t^3.$$

Temp. C.	Obs. vol.	Calc. vol.	Diff.
°0·00	6177·89	6177·99	+0·10
3·24	6178·40	6178·37	−0·03
6·45	6179·68	6179·61	−0·07
9·64	6181·62	6181·62	0·00
12·79	6184·33	6184·30	−0·03
15·85	6187·50	6187·53	+0·03
18·87	6191·41	6191·25	−0·16
21·98	6195·54	6195·59	+0·05
24·98	6200·09	6200·20	+0·11
*28·13 β	6205·25	6205·46	+0·21
31·12	6210·65	6210·77	+0·12
34·32	6217·07	6216·76	−0·31
36·71	6222·06	6221·38	−0·68

TABLE IX.

Sample D. Series II.

Dilatometer O. Thermometer A.

$$V = 6188{\cdot}329 + 0{\cdot}030506t + 0{\cdot}03823208t^2 - 0{\cdot}000171645t^3.$$

Temp. C.	Obs. vol.	Calc. vol.	Diff.
°0·00	6188·23	6188·33	+0·10
2·94	6188·78	6188·74	−0·04
4·50	6189·28	6189·22	−0·06
7·50	6190·65	6190·64	−0·01
10·42	6192·63	6192·60	−0·03
14·99	6196·75	6196·80	+0·05
17·35	6199·49	6199·47	−0·02
20·96	6204·10	6204·18	+0·08
23·83	6208·50	6208·44	−0·06
26·59	6212·90	6212·94	+0·04
29·84	6218·72	6218·72	0·00
32·92	6224·68	6224·64	−0·04

The numbers in the fourth columns in each of the preceding Tables being satisfactorily small, the next step was to compare the expressions obtained from the different series of experiments on the same solution. For this purpose L, M, and N in each of the formulæ were divided by the corresponding values of K, and series of equations were thus obtained of the form

$$v=1+l't+m't^2+n't^3,$$

giving the apparent expansion for each solution.

These equations were then corrected for the alterations in the volumes of the dilatometers due to the changes of temperature, the coefficients of expansion being taken to be

for dilatometer O . . . . . . 0·00002459,
" " P . . . . . . 0·00002382

for 1° C. being between 0° and 40°. The resulting expressions, of which

$$v=1+lt+mt^2+nt^3$$

may be taken as the type, give the true expansions of the solutions as deduced from the separate series of experiments.

The values of l, m, and n are given in Table X.

Table X.

Sample.	Series.	l.	m.	n.
A.	I.	·000087677	·0000047604	–·000000012121
	II.	·000074867	·0000054370	–·000000024334
B.	I.	·000057682	·0000060715	–·000000032983
	II.	·000058352	·0000059171	–·000000029871
	III.	·000052849	·0000061299	–·000000033281
C.	I.	·000041889	·0000061650	–·000000030763
	II.	·000039989	·0000063468	–·000000035571
D.	I.	·000020391	·0000071663	–·000000050546
	II.	·000029520	·0000061782	–·000000027585

The following Table shows the volumes calculated for a few temperatures by the aid of these constants.

TABLE XI.

$t°$ C.	Sample A.		Sample B.			Sample C.		Sample D.		$t°$ C.
	Series I.	Series II.	Series I.	Series II.	Series III.	Series I.	Series II.	Series I.	Series II.	
0	1·00000	1·00000	1·00000	1·00000	1·00000	1·00000	1·00000	1·00000	1·00000	0
2	19	17	14	14	13	11	11	7	8	2
4	43	39	32	32	31	26	26	19	21	4
6	69	64	56	56	53	47	46	37	39	6
8	100	93	83	83	80	71	71	60	62	8
10	134	127	115	115	111	100	100	87	89	10
12	171	164	151	150	146	134	133	119	120	12
15	237	226	212	211	206	191	191	175	174	15
18	305	297	281	279	274	257	257	239	237	18
21	383	375	358	356	351	332	331	312	309	21
24	468	459	443	440	434	413	412	392	388	24
27	559	551	533	530	524	502	501	478	476	27
30	659	648	630	627	621	598	595	570	570	30
33	764	752	733	730	722	699	695	666	671	33
36	876	861	841	838	830	806	801	766	778	36

The agreement between the numbers referring to the same solution in these Tables may be considered satisfactory; the greatest differences, which are observed in the case of sample A, may in part be due to the fact that, unfortunately, in Series I. no observations could be made at temperatures below 7°; but as we have adopted the means of the different equations obtained for each series as the true expressions of the expansions, and as these formulæ are, as we shall see hereafter, connected together by a simple relation, which that referring to A obeys on the whole satisfactorily, we have not thought it necessary to repeat the experiments, as those already obtained prove sufficiently accurate for our purpose when thus checked.

The mean values of the constants given in Table X. are exhibited in Table XII., and are the coefficients of the powers of t in the formulæ we adopt as expressing in each case the relation between the volumes and the temperatures of the solutions submitted to experiment, and to which we shall hereafter refer as the *mean* formulæ.

TABLE XII.

	l.	m.	n.
A.	·000081272	·0000050987	—·000000018227
B.	·000056294	·0000060395	—·000000032045
C.	·000040939	·0000062559	—·000000033167
D.	·000024955	·0000066723	—·000000039065

Expressions for the expansions of the individual solutions having been thus obtained, it only remained to investigate a formula embracing them all as particular cases of a relation between the temperature, volume, and salinity of sea-water as measured by its specific gravity at 0°. Table XIII. was therefore prepared: it shows, side by side, for purposes of comparison, the volumes of the samples A, B, C, and D at a few temperatures, that at 0° C. being in each case supposed to be unity.

TABLE XIII.

$t°$.	A.	B.	C.	D.
6	1·00066	1·00055	1·00046	1·00038
10	131	114	100	88
15	232	210	191	174
21	379	355	331	310
27	555	529	501	477
33	758	728	697	668

The differences between consecutive columns in this Table multiplied by 10^5 give us the following numbers:—

$t°$.	A−B.	B−C.	C−D.
6	11	9	8
10	17	14	12
15	22	19	17
21	24	24	21
27	26	27	24
33	30	31	29

Dividing the numbers in each of these columns by those in that which follows it, we obtain the quotients (correct to one place of decimals)—

$$\frac{A-B}{B-C}=1{\cdot}2 \quad 1{\cdot}2 \quad 1{\cdot}1 \quad 1{\cdot}0 \quad 1{\cdot}0 \quad 1{\cdot}0$$

$$\frac{B-C}{C-D}=1{\cdot}1 \quad 1{\cdot}2 \quad 1{\cdot}1 \quad 1{\cdot}1 \quad 1{\cdot}1 \quad 1{\cdot}1$$

The numbers in these two groups are, to within the limits of the error of experiment, constant.

Accordingly we may assume that if v, v', and v'' are the volumes at the same temperature of quantities of the solutions, the volume of each of which at 0° C. is unity, the value of $\frac{v-v'}{v'-v''}$ is independent of the temperature, and is therefore, if the solutions to which v' and v'' refer are supposed to be always the same, a function of s (the specific gravity of the third solution at 0° C.) only, so that

$$\frac{v-v'}{v'-v''}=f(s). \qquad (1)$$

Secondly, noticing that the numbers in each of the above groups are approximately equal to each other and to unity, and bearing in mind the fact that the differences between the specific gravities of the solutions employed, which are

$$\cdot 004355,\ \cdot 003748,\ \text{and}\ \cdot 004160$$

respectively, differ in the fourth place of decimals, we are led to the conclusion that $f(s)$ is a linear function of s, and that differences in the fourth place of decimals in the value of the specific gravities do not involve important changes in the law of thermal expansion.

From this it follows that equation (1), when written at length, is of the form

$$v=1+bt+ct^2+dt^3+(b't+c't^2+d't^3)(p+qs), \quad \ldots\ldots\ldots \quad (2)$$

or

$$v=\phi(t)+\psi(t)f(s)^*.$$

As this expression is of no theoretical value, it is unnecessary to describe, step by step, the arithmetical operations by which the constants were determined; it is sufficient to say that a larger number of equations than that required for the purpose may be obtained by equating the coefficients of t in (2) to their values as determined for the solutions submitted to experiment and given in Table XII., and that the numbers given by the equations of condition so obtained have been in some cases slightly modified. The values taken were:—

$$b=\ \cdot 00008097, \qquad b'=-\cdot 5509\times 10^{-5},$$
$$c=\ \cdot 0000049036, \qquad c'=\ \cdot 020198\times 10^{-5},$$
$$d=-\cdot 000000012289, \qquad d'=-\cdot 00033276\times 10^{-5}.$$

The expression $p+qs$ may be conveniently written in the form

$$11\cdot 95-940\,(s-1\cdot 02),$$

in which it is unnecessary to express s to more than 4 places of decimals. Table XIV. shows the agreement between the volumes calculated by the mean formulæ and the general expression thus determined.

TABLE XIV.

	Sample A.			Sample B.			Sample C.			Sample D.		
t° C.	Mean formula.	General formula.	Diff.	Mean formula.	General formula.	Diff.	Mean formula.	General formula.	Diff.	Mean formula.	General formula.	Diff.
0	1·00000	1·00000	0	1·00000	1·00000	0	1·00000	1·00000	0	1·00000	1·00000	0
2	18	18	0	14	14	0	11	10	−1	7	7	0
4	41	40	−1	32	33	+1	26	26	0	20	19	−1
6	66	66	0	55	56	+1	46	47	+1	38	36	−2
8	96	95	−1	82	83	+1	71	72	+1	61	58	−3
10	131	130	−1	114	115	+1	100	101	+1	88	86	−2
12	167	167	0	149	150	+1	133	135	+2	119	118	−1
15	232	229	−3	210	209	−1	191	191	0	174	173	−1
18	301	298	−3	278	277	−1	257	258	+1	238	237	−1
21	379	376	−3	355	353	−2	331	333	+2	310	310	0
24	463	461	−2	439	437	−2	412	415	+3	390	390	0
27	555	553	−2	529	527	−2	501	503	+2	477	477	0
30	653	652	−1	626	623	−3	596	597	+1	570	569	−1
33	758	758	0	728	726	−2	697	697	0	668	665	−3
36	869	870	+1	836	834	−2	803	802	−1	772	766	−6

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[*] The numerical constants involved in the above formula are given in the forms in which they were, for facility of calculation, determined. The expression can, of course, be easily transformed to the simpler form, $V=F_1(t)+s\,F_2(t)$.

This Table amply verifies the accuracy of the general formula over the range of the experiments; and it has accordingly been employed to calculate Table XV., in which the results of the investigation are summed up.

The values of the functions of t on which the value of v depends were first determined for every integral value of t between 0° and 36°, and the value of $f(s)$ was calculated when s was put equal to 1·02 and 1·03, and also for several intermediate values of the variable. The different numbers given by $\psi(t)$ were multiplied by the values of $f(s)$ in succession, and the results being added (algebraically) to the corresponding values of $\phi(t)$, gave the values of v for the selected temperatures and specific gravities.

The specific gravities at the different temperatures (σ) were then obtained by means of the formula

$$\sigma v = s.$$

Writing this in the form

$$\sigma = \frac{s}{\phi(t) + \psi(t)(p + qs)},$$

it is easy to show, by considering the different possible values of $\phi(t)$, $\psi(t)$, and s, that $\frac{d\sigma}{ds}$ is for the range of the observations so nearly constant that no error greater than ·00002 could be introduced into the calculated specific gravities by the assumption that it is independent of s; and the values of σ calculated for the different selected values of s prove that this superior limit is really considerably in excess of the true error, and that therefore we may with safety assume that $\frac{d\sigma}{ds}$ is constant.

We are therefore able to give in Table XV. all the data necessary to calculate the specific gravity of sea-water of any degree of salinity at any temperature between 0° and 36°. Column II. contains the specific gravities at the temperatures given in column I. of a solution the specific gravity of which at 0° C. is 1·02000; column III. contains the numbers which must be subtracted from those in column I. for each increase of 1°·0 over the temperatures opposite to which they are placed; and column IV. the numbers which must be added for each increase of ·00001 of the specific gravity of the solutions at zero. At the head of columns III. and IV. are the numbers of ciphers which must be prefixed to the figures written in them in the unit place.

Table XV.

I. Temperature.	II. Specific Gravity.	III. Proportional parts for 1° C.	IV. Proportional parts for ·00001 increase in sp. gr.	I. Temperature.	II. Specific Gravity.	III. Proportional parts for 1° C.	IV. Proportional parts for ·00001 increase in sp. gr.
		·0000	·0000			·0000	·0000
0°	1·02000	3	1	19°	1·01740	25	0·944
1	1·01997	4	0·995	20	1·01715	25	0·943
2	1·01993	5	0·990	21	1·01690	26	0·941
3	1·01988	6	0·986	22	1·01664	27	0·940
4	1·01982	8	0·982	23	1·01637	28	0·938
5	1·01974	9	0·979	24	1·01609	29	0·937
6	1·01965	11	0·975	25	1·01580	29	0·935
7	1·01954	12	0·972	26	1·01551	30	0·934
8	1·01942	13	0·969	27	1·01521	30	0·932
9	1·01929	14	0·966	28	1·01491	31	0·930
10	1·01915	15	0·963	29	1·01460	32	0·928
11	1·01900	17	0·961	30	1·01428	32	0·925
12	1·01883	17	0·958	31	1·01396	32	0·922
13	1·01866	19	0·956	32	1·01364	33	0·919
14	1·01847	20	0·954	33	1·01331	33	0·915
15	1·01827	21	0·952	34	1·01298	33	0·912
16	1·01806	21	0·950	35	1·01265	34	0·908
17	1·01785	22	0·948	36	1·01231	34	0·903
18	1·01763	23	0·946				

In order to facilitate the use of the Table we subjoin directions for its application in the form of rules, and give a couple of examples.

Given the specific gravity of a sample of sea-water at any temperature t, to find it at 0° C.:—Look out in column I. the figure giving the number of entire degrees of the temperature; multiply the fraction (if any) by which the observed temperature exceeds that number by the corresponding number in III., and subtract the result from the corresponding number in column II. Subtract the difference from the observed specific gravity, and divide the number so obtained by that corresponding to the observed temperature in column IV. (without prefixing the ciphers at the top of the column); add the quotient to 1·02000, and the sum will be the specific gravity required.

Example I. Specific gravity observed at 18°·5 C.=1·02475. To find it at 0° C., number opposite 18 in column III. is ·00023, which multiplied by ·5 equals ·000115; and

$$1{\cdot}017630-{\cdot}000115=1{\cdot}017515.$$

Subtract this from the observed specific gravity,

$$1{\cdot}024750-1{\cdot}017515={\cdot}007235.$$

Divide by ·945, and the quotient is ·00765, which added to 1·02000 gives 1·02765 as the specific gravity at 0° C.

Example II. Specific gravity observed at 15° =1·02570. To find it at 0° C.,

$$1{\cdot}02570-1{\cdot}01827={\cdot}00743,$$

and

$$\frac{{\cdot}00743}{{\cdot}952}={\cdot}00780.$$

Therefore specific gravity at 0°=1·02000+·00780=1·02780.

Having thus linked together the results of our observations under one general law, it remains to compare our conclusions with those of Prof. Hubbard, whose investigation is, as we have already stated, the only one which covers the same ground as our own.

If, as Mr. Buchanan points out, the specific gravities of different specimens of sea-water vary only between 1·0278 and 1·0240, the results to be of value must be correct to the fourth decimal place; obviously therefore the formulæ of reduction ought to be as accurate as the experiments themselves.

In Maury's work Professor Hubbard's Table of the thermal dilatation of sea-water extends from 22° F. to 200° F., the volume of water at 60° F. being taken as unity. In order to compare it with our own, we have transcribed the portion contained between 22°F.(−5°·5 C.) and 95° F. (36° C.), making the volume at 0° the unit, as in our own Table.

Table XVI.

° C.	Hubbard.	T. & R.	° C.	Hubbard.	T. & R.
−5·55	1·00012		+2·0	1·00009	1·00014
5·00	1·00006		4·0	25	33
4·44	1·00003		6·0	45	56
3·89	1·00000		8·0	71	83
3·33	0·99998		10·0	98	115
2·78	0·99997		12·0	132	150
2·22	0·99996		15·0	192	209
1·67	0·99996		18·0	265	277
1·11	0·99997		21·0	343	353
0·56	0·99998		24·0	430	437
0·00	1·00000	1·00000	27·0	526	527
			30·0	626	623

A glance at the two columns shows that the volumes do not agree to within the limits of error above indicated, the numbers being approximately the same for the higher and lower but widely divergent for intermediate temperatures. Mr. Hubbard's observations were made by a method substantially the same as our own, but the results are affected by a circumstance which might at first sight be supposed to conduce to their accuracy. Mr. Hubbard employed unusually large volumes of sea-water in his experiments; but it should be noted, as indeed Kopp has already pointed out, that in such observations the increased difficulty of obtaining a uniform temperature throughout the entire mass more than compensates for the accuracy arising from the greater displacement of the liquid column. The stems of Mr. Hubbard's instruments were not graduated, the readings being taken from attached scales, probably of wood or metal. Moreover, in the reduction, the inaccurate coefficient of expansion of mercury given by Dulong and Petit was employed. These circumstances may probably serve to account for the discrepancies between the two sets of observations. At all events we may point out that it would seem almost impossible that errors of the magnitude of the discrepancies we are discussing can occur in our own results. Taking as an example the particular case of 15° C., where the difference between the two values is large, and referring to Table XI., we see that the three values of the volume we obtained by three independent series of experiments were 1·00212, 1·00211, and 1·00206, and that the general formula gives 1·00209, which is, to within a fraction in the fifth place, equal to the mean of the three observations, and certainly cannot be affected with so great an error as 17 in the fifth place, which is, however, the difference between it and Prof. HUBBARD's number.

We may also point out that it appears from Prof. HUBBARD's Table that the point of maximum density of average sea-water is 28°·5 F. or —1°·94 C. If we compare this result with other observations on record, we find that it is probably between 2° and 3° C. too high. Excluding MUNCKE's result of —5°·25, which is probably too low, we find that DESPRETZ obtained —3°·67 (which is probably too high for average sea-water), NEUMANN —4°·74 in the case of a mixture of sea-water from Trieste, Genoa, and Heligoland, and ROSSETTI —3°·90 in that of Adriatic water of specific gravity 1·02814 at 0°. The number obtained from our general formula, viz. —5°·14, is probably too low by at least 0°·5 C.; but it is necessary to remember that the formulæ we give are based on observations between 0° and 36°, and are only applicable to temperatures between these limits.

It is quite evident from the foregoing observations that the laws of the thermal expansion of all ocean sea-waters cannot be assumed to be sensibly the same. The difference at 15° between the volumes of sea-waters of specific gravities 1·024 and 1·0278 is 18 in the fifth place; at 30° it is 26; so that even the use of the formula corresponding to the mean of the two numbers would, for high temperatures and relatively weak or strong solutions, introduce errors in the fourth place of decimals, whence it follows that the alterations in the law of thermal expansion depending on the salinity of the solutions cannot be neglected.

XVII. THE BAKERIAN LECTURE.—*On the Gaseous State of Matter.*

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§ 1.

SINCE the investigation "On the Continuity of the Gaseous and Liquid States of Matter," which formed the subject of the Bakerian Lecture for 1869, was communicated to the Society, I have continued to pursue the inquiry in a more extended form, with the view of discovering the general laws which determine the physical conditions of matter in the gaseous and liquid states. The subject in its whole extent and under all its aspects is so vast in itself, and its investigation in many cases has been surrounded by experimental difficulties of so high an order, that I must crave the indulgence of the Society if the amount of work actually accomplished appear small for the time devoted to it. I will give in the first place a few details regarding the method of mounting the apparatus, which will aid greatly any one who may hereafter desire to pursue the inquiry.

The apparatus employed is, in all the essential parts, the same as that which I formerly described. The packing of the steel screw, by which the pressure is produced, is an important part of the operation. It is effected by means of a number of circular disks of leather, pierced centrally with a fine hole, and rendered impervious to water by being saturated *in vacuo* with melted lard. These disks are introduced, one by one, into a cylindrical cavity above the female screw in the lower end-piece, care being taken to press down each disk separately by a few gentle blows of a wooden mallet. After the introduction of the leather packing, the brass end-piece is placed with the face downwards on a small wooden block, and the whole is firmly clamped to a steady bench or table. The steel screw is then inserted, and screwed through the leather packing till it enters into the wooden block. The connexion between the metal and glass tube in the upper end-piece is established by forming a protuberance on the glass tube accurately corresponding to a conical surface in the passage through the end-piece. The conical surface of the glass tube and the adjoining cylindrical surface for an inch and a half below the cone were covered with several layers of fine thread coated with ordinary shoemaker's wax. The brass end-piece was gently heated before the introduction of the glass tube, and the latter was firmly fixed in its place by steady pressure. So perfectly have these arrangements fulfilled their purpose, that the apparatus, when successfully mounted, will remain in perfect order and without a trace of leakage for an indefinite period of time. The greatest pressure to which I have exposed the apparatus is 500 atmospheres, but it would be easy with very fine glass tubes to make accurate observations even at much higher pressures.

As the metallic tubes, whether made of cold-drawn copper or of forged iron, which form the body of the apparatus are, as at present constructed, $\frac{5}{8}$ of an inch in internal diameter, I have been able to make an important improvement in the arrangements. The glass tubes containing the gases now dip into small mercurial reservoirs formed of thin test-tubes, which rest on ledges within the metal tubes. This arrangement has prevented many failures in screwing up the apparatus, and has given greater precision to the measurements.

In the following experiments the glass tube was filled with the gas in a pure and dry state by passing a stream for a long time through it while in an upright position; and when the air was entirely expelled, the upper end was hermetically sealed. The stream of gas being still maintained across the lower end of the tube, which was enclosed in a test-tube partly filled with mercury, the whole apparatus was left for half an hour in an apartment at a steady temperature, after which the gas was imprisoned at a known temperature and pressure, by bringing the lower or open end of the tube into contact with the surface of the mercury in the test-tube. By this process the original volumes of air in the manometer, and of carbonic acid in the carbonic acid tube, could be fixed with great accuracy.

The capacities of the entire tubes and of their capillary parts were ascertained by a set of careful determinations of the weight of mercury which filled them at a known temperature. Before the introduction of the mercury, the interior of each tube was carefully cleansed by boiling nitric acid in it, and afterwards washing it with distilled water and absolute alcohol. No attempt was made to remove by boiling the thin film of air which, even in the most carefully cleansed tube, is always interposed between the surface of the glass and the mercury drawn into the tube. Under the conditions of these experiments this correction must be very small; and its estimation would be a matter of extreme difficulty, as in screwing up the apparatus air of different densities would be imprisoned between the glass and mercury. On a future occasion I hope to lay before the Society the results of a special investigation of this subject. The average capacity of the capillary part of the tube of the air-manometer used in the greater number of the following experiments was for 1 millimetre 0·00018121 cubic centimetre, and this tube bore a pressure of upwards of 200 atmospheres without bursting. I have completed a series of experiments at higher pressures, which I hope soon to communicate to the Society, with a hydrogen manometer, whose capacity for each millimetre was only 0·000016861 cubic centimetre, or $\frac{1}{11}$ of the preceding. Such a tube would bear a pressure many times greater than the former, and no serious difficulty would arise in operating with even finer tubes. There is therefore scarcely any limit to the pressures which may be measured in glass tubes. The glass of which these tubes were made was of excellent quality, and was specially prepared for me by J. Powell and Sons.

No pains were spared in calibrating the capillary portions of the tubes. For this purpose a dividing and calibrating engine was employed, which was devised some years ago by myself. It was provided with a short steel screw of remarkable accuracy, specially constructed for this dividing engine by TROUGHTON and SIMMS. The results of the calibration were [plotted on a large scale, and the small errors arising from the abrupt passage between the calibrated lengths of the tube were estimated by a simple method, for which I am indebted to my friend Professor JAMES THOMSON. The thermometers employed were the same to which I formerly referred. They were all calibrated and divided by myself, and their agreement throughout the whole range between 0° and 100° was almost perfect. The shifting of the zero-points has not been considerable, but it was carefully observed from time to time.

The capacity c_0 of the glass tube at 0° C. in cubic centimetres was calculated by the following equation, in which w is the weight of the mercury, t the temperature at which the observation was made, and f (0·000158) the apparent dilatation for 1° C. of mercury in glass:—

$$c_0=w\cdot\frac{1+ft}{13\cdot596}. \quad \ldots\ldots\ldots\ldots \quad (1)$$

The value of c_0, as given by this expression, may be used without notable error for temperatures differing only by a few degrees from 0° C., but at high temperatures a correction is required for the expansion of the glass vessel. If the readings had been made by means of fine divisions etched on the tube, this correction would correspond to the cubic expansion of the glass; but when, as in my method of working, cathetometric readings are made from the extreme end of the internal cone above to the bounding surface of the mercury below, the correction will be the difference between the cubic and linear expansion of glass, or for small differences of this order it will be two thirds of the cubic expansion. If c_t be the capacity at the temperature t, k the cubic dilatation of glass for 1° C. (0·0000272), we shall have, under the conditions stated above,

$$c_t=c_0(1+\tfrac{2}{3}kt). \quad \ldots\ldots\ldots\ldots \quad (2)$$

Combining equations (1) and (2), we obtain a general expression for c_t,

$$c_t=w\cdot\frac{1+ft}{13\cdot596}(1+\tfrac{2}{3}kt). \quad \ldots\ldots\ldots\ldots \quad (3)$$

The original volume of gas at 0° and 760 millimetres was calculated by the usual formula,

$$v_0=v_t\cdot\frac{1}{1+\alpha t}\cdot\frac{p}{760} \quad \ldots\ldots\ldots\ldots \quad (4)$$

where v_t is the capacity of the tube in cubic centimetres, α the coefficient of expansion at the ordinary pressure of the atmosphere (0·00367 for air and 0·00371 for carbonic acid), t the temperature of the observation, and p the height of the barometer reduced to 0° C. and the latitude of 45°.

The pressure in atmospheres, as indicated by the air-manometer, on the gas in the carbonic acid tube was given by the equation

$$p=\frac{V_0(1+\alpha t)}{V_1}\mp\frac{q}{760}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

in which V_0 is the volume of the air at 0° and 760 millimetres, V_1 the observed volume at the temperature t, and q the difference of level (corrected when necessary for difference of capillary depression) of the surface of the mercury in the manometer and carbonic acid tubes, the negative sign applying to the case in which the mercury stands higher in the carbonic acid tube than in the manometer.

The value of ε, which is the ratio of the volume of the carbonic acid at the pressure p (as indicated by the air-manometer) and temperature t' to its volume *at the same temperature* t' under one atmosphere, is given by the equation

$$\varepsilon=\frac{V_1}{V_0(1+\alpha t')}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

If we represent by θ the volume to which one volume of carbonic acid measured at 0° and 760 millimetres is reduced at the pressure p and temperature t', we shall have

$$\theta=\frac{V_1}{V_0}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

It was manifestly impossible, at the great pressures employed, to surround the manometer and carbonic acid tubes with outer tubes of glass subjected internally to the same pressure, so as to equalize the pressure on both sides of the glass. Nor would any useful purpose have been attained if such an arrangement had been possible, as the thickness of the glass walls of the capillary tubes was never less than eight times the diameter of the bore, and any change in the capacity would be too small to affect sensibly the results. From a long series of experiments undertaken for the purpose of making a new determination of the compressibility of mercury, but not yet completed, I will give only the following result, as being sufficient for our present purpose:—A column of mercury 445 millimetres in length was exposed in a tube with a fine capillary bore to a pressure ranging from 5 to 110 atmospheres, at the temperature of 17°·60, the temperature scarcely varying 0°·01 during the experiments. The apparent change of volume for one atmosphere was found to be

0·0000070.

In a repetition of the same experiment at 18°·55, the result was

0·0000072.

From a series of experiments between 3·3 and 9·5 atmospheres of pressure, REGNAULT has calculated the absolute compressibility of mercury by the aid of a set of equations which were furnished to him by M. LAMÉ, and found it to be

0·0000035.

Although this latter result can only be regarded as an approximation to the truth, from the limited range of pressure employed, as well as from the uncertainty of some of the principles upon which the mathematical expressions depend, it may be taken to be sufficiently accurate for our present purpose. Combining it with the mean of the two foregoing numbers, we obtain for the change of internal capacity of the glass tube for one atmosphere of pressure

$$K=0{\cdot}0000036.$$

From other experiments it would appear that the value of K diminishes as the pressure increases, a result which might be expected from the change of volume being chiefly due to the yielding of the inner layers of the glass of which the tube was composed. For 100 atmospheres the entire correction would, according to these experiments, amount only to $\frac{1}{3000}$ part. I have not thought it necessary to apply this correction, as it falls in most cases within the limits of the errors of observation; but the data I have given are sufficient to allow this omission to be readily supplied.

I have deemed it important to attempt the solution of a problem of the highest interest in itself and of the greatest importance to the accuracy of many fundamental determinations in physics and chemistry, but which, so far as I know, has never been made the subject of direct investigation. It is to ascertain whether mercury has to any extent the property of absorbing gases in the same manner as water and alcohol. The fact that gases like ammonia, which are largely absorbed by water, may be readily collected and preserved over mercury, and the absence of any diminution of volume in gaseous mixtures standing for long periods of time over mercury, rendered it highly improbable that any such absorption would take place. It was, however, important to ascertain whether under great pressures any indications of absorption could be found. The following is the way in which I have attempted to resolve this question.

Having reduced the pressure to 10 atmospheres in the apparatus, mounted with an air-manometer and carbonic acid tube, I allowed it to remain undisturbed at this low pressure for ten days. At the end of this time, on a sunless day, which favoured accurate observations, water was made to circulate from a large cistern, at a steady temperature of 8°·39, through the rectangular vessels which enclosed the tubes; and the pressure was then quickly raised from 10 atmospheres till half a millimetre of liquid was formed in the carbonic acid tube. The air-manometer was then read, and the apparatus left at the new pressure for five days. It was again adjusted carefully, so that half a millimetre of liquid carbonic acid was formed as before. The temperature at this reading was 8°·45. The calculated pressures, from the indications of the air-gauge, were on the first occasion 43·94 and on the last 44·00 atmospheres. A difference of pressure of 0·06 atmosphere corresponded therefore to a difference of temperature of 0°·06. From experiments to be described in a future communication, it will appear that at this pressure a change of 0·06 atmosphere corresponds to 0°·055. The agreement is complete, and the air in the manometer had therefore undergone no diminution of volume or absorption, after an interval of five days, from a change of pressure from 10 to 44 atmospheres.

Having thus shown that air is not absorbed by mercury, it remained to extend the inquiry to the case of carbonic acid gas. For this purpose the apparatus was again left at a pressure of 10 atmospheres for some days, and the pressure was then quickly raised at 4°·99 to 35·89 atmospheres, at which pressure the carbonic acid was still wholly in the gaseous state. After reading the volumes of air and carbonic acid gas in the two tubes, the apparatus was left at the new pressure for two days, when the observation was repeated at the same temperature, the pressure having been adjusted as at the first observation. The readings of the two tubes were precisely the same as before. Now as the former experiments had proved that the air in the manometer under increased pressure undergoes no absorption, the last experiment evidently extends this conclusion to carbonic acid gas. In confirmation of this result, I may mention that after allowing the apparatus to stand for many hours at a pressure of above 100 atmospheres, and then suddenly reducing the pressure to 10 atmospheres, not the slightest evidence of the escape of gas from the surface of the mercury could be detected even with the aid of a strong magnifier. In filling a barometer-tube the air which is expelled by ebullition has not been dissolved in the mercury, but comes from the thin shell of air interposed between the mercury and the surface of the glass.

Two questions still remain to be considered. 1. Do the glass tubes undergo a permanent increase of capacity when exposed for a long time to these high pressures? 2. Is there any absorption of oxygen in the air-manometer from its slow combination with the mercury? To both questions I am able to give a satisfactory answer. The apparatus was mounted on October 30, and three days after the pressure at which carbonic acid liquefies when the temperature is 8°·41 was found in two experiments to be 43·90 and 43·94 atmospheres, the mean being 43·92 atmospheres. During the following two months the apparatus was in daily use for a long course of experiments, in which the pressures varied from 12 to 120 atmospheres, and the latter pressure was often maintained for the space of 24 hours. On the 1st of January the pressure required for liquefaction was again determined at the same temperature of 8°·41. In three experiments it was found to be 43·96, 43·96, and 43·94 atmospheres—the mean, or 43·95 atmospheres, differing only by 0·03 atmosphere from the former result. This is quite within the limits of error of observation, as it corresponded to a difference of less than 0·1 millimetre in the actual readings. It follows therefore that there has been no appreciable enlargement of the internal capacity of the tube, or reduction of the volume of the air from chemical combination or absorption, during a period of two months of active work. That no oxidation of the mercury had occurred was further shown by the bright metallic surface of the fine mercurial column, and the absence of any tendency to drag when the mercury rose or fell from change of pressure*.

It is with regret that I am still unable to give the true pressures which correspond to the indications of the air-manometer. Since my former communication in 1869, I have given the most careful consideration to this subject, and I hope soon to submit to the Society a detailed statement of the only method by which, as far as I can discover, this highly important question can be resolved for high pressures. Even for pressures under 30 atmospheres the discordant results at which such distinguished physicists as OERSTED and SWENDSEN, ARAGO and DULONG, and REGNAULT have arrived, afford ample proof of the extraordinary difficulties of the investigation*. I shall have occasion presently to recur to this subject, and to refer to the attempts which have since been made by other methods to ascertain the compressibility of air and of the permanent gases at high pressures. In the absence of precise data, I have not attempted in this paper to correct the indications of the air-manometer so as to reduce them to true pressures. We shall see hereafter that up to 250 atmospheres there is good reason for believing that the deviations of the air-manometer from true pressures are not considerable, or such as to interfere with any general conclusions.

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* While writing the above I have carefully examined the apparatus, and find it to be now in as perfect order as when it was mounted five months ago, the mercury in the air-manometer moving through its extreme range as readily and with as much precision as in a thermometer of the best construction.—[March 22.]

In the present investigation on the properties of the gaseous state of matter I have, as in my former researches, selected carbonic acid gas (CO_2) for experiment, partly from the facility with which it can be prepared in a state of purity, but chiefly from its critical temperature being only 31° above the freezing-point of water. It may fairly be taken as a typical representative of the gaseous state, and, as we shall see, it is in a condition peculiarly favourable for the discovery of the laws which govern the action of the internal or molecular forces in that state. The experiments of OERSTED and SWENDSEN, of DESPRETZ and of POUILLET, have shown that when exposed to increasing pressure it deviates sensibly from the law of BOYLE; and REGNAULT has measured with precision its compressibility at 3° for pressures reaching to 27 atmospheres, and has likewise confirmed the observation of VON WREDE, that even at pressures below one atmosphere it deviates sensibly from BOYLE's law.

The carbonic acid gas was prepared by the action of pure and dilute sulphuric acid, deprived of its air by boiling, upon marble. It was carefully desiccated by passing through a U-tube filled with fragments of pumice freed from chlorides, and moistened with pure sulphuric acid. In Tables I., II., and III. will be found the results of a large number of experiments on the compressibility of carbonic acid at temperatures differing little respectively from 6°·5, 64°, and 100°. For the lower temperature a stream of cold water from a large cistern was made to flow at a uniform rate around the carbonic acid tube. The manometer-tube was kept at a steady temperature by a similar arrangement. The temperature of 64° was obtained by passing the vapour of pure and anhydrous methyl-alcohol through the apparatus*. About two thirds of a litre of the alcohol was distilled over in each observation, the temperature being observed by one of the thermometers before referred to. The temperature obtained in this way, after every precaution has been taken, is far from being so steady as that given by the vapour of water; but with a little care very accurate determinations can be made. A deduction of 0°·14 was made from the direct reading as a correction for the error of the thermometer due to irregular expansion of the mercury.

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* ARAGO and DULONG inferred from their experiments, extending from 1 to 27 atmospheres, that the law of BOYLE is strictly true in the case of air; and the same conclusion was also drawn by OERSTED and SWENDSEN from their own experiments. From a careful analysis of their results, as given in the original memoir of ARAGO and DULONG (Mémoires de l'Académie des Sciences, x. p. 207), it appears to me that their experiments rather indicate a deviation from the law of BOYLE, but to not more than one third of the amount given by the subsequent researches of REGNAULT (Mém. de l'Acad. des Sciences, xxi. p. 421).

For temperatures about 100°, vapour of water from a boiler in an adjoining apartment was passed around the carbonic acid tube and conveyed away by an exit-pipe through an outer wall of the apartment. Its pressure when in the vessel around the carbonic acid tube was usually about 50 millimetres of water above that of the atmosphere, as ascertained by a U-shaped water-gauge connected with the apparatus. By adding the pressure indicated by the water-gauge to the height of the barometer, the elastic force of the steam, and consequently its temperature, was known.

In the following tables I have recorded the results of direct experiments, all made by myself, and reduced by the equations already given. In every case two experiments at least, and often more than two, were made, the apparatus being thrown out of adjustment and readjusted between each observation. The mean numbers given in the tables scarcely differed by an appreciable amount from the results of the individual experiments.

In Tables I., II., and III., p is the pressure in the carbonic acid tube calculated from the indications of the air-manometer, t the temperature of the manometer, ε the ratio of the observed volume of the carbonic acid at the pressure p and temperature t' to its volume at the same temperature t' under a pressure of one atmosphere, t' the temperature of the carbonic acid, and θ the volume to which one volume of carbonic acid, measured at 0° and under one atmosphere, is reduced at the pressure p and temperature t'. By one atmosphere of pressure is meant the pressure of a column of mercury 760 millimetres in length measured at 0° and under the latitude of 45°.

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* Both the air-tube and carbonic acid tube were enclosed in rectangular brass vessels, having plate-glass sides inserted before and behind, by which means accurate readings, not attainable in ordinary glass cylinders, were secured. Through these rectangular vessels the water or vapour circulated, by means of which the tubes were maintained at fixed temperatures. A detailed description, with a figure of the apparatus, will be found in my former communication, Philosophical Transactions for 1869, p. 578.

Table I.—Compressibility of Carbonic Acid Gas.—6°·0–6°·9.

p.	t.	ϵ.	t'.	θ.
12·01	6°·91	$\frac{1}{12{\cdot}95}$	6°·89	0·07921
13·22	6·90	$\frac{1}{14{\cdot}26}$	6·90	0·07143
14·68	6·90	$\frac{1}{16{\cdot}12}$	6·90	0·06364
17·09	6·45	$\frac{1}{19{\cdot}12}$	6·44	0·05371
20·10	6·79	$\frac{1}{23{\cdot}01}$	6·79	0·04456
22·26	6·07	$\frac{1}{25{\cdot}99}$	6·05	0·03934
24·81	6·72	$\frac{1}{29{\cdot}60}$	6·73	0·03462
27·69	6·07	$\frac{1}{34{\cdot}09}$	6·05	0·02999
31·06	6·65	$\frac{1}{39{\cdot}57}$	6·62	0·02589
34·49	6·03	$\frac{1}{45{\cdot}96}$	6·02	0·02224

Table II.—Compressibility of Carbonic Acid Gas.—63°·6–64°·0.

p.	t.	ϵ.	t'.	θ.
17·60	9°·30	$\frac{1}{18{\cdot}57}$	63°·86	0·06671
20·36	9·19	$\frac{1}{21{\cdot}66}$	63·76	0·05710
22·56	8·82	$\frac{1}{24{\cdot}19}$	63·79	0·05113
25·06	8·82	$\frac{1}{27{\cdot}09}$	63·77	0·04564
28·07	8·85	$\frac{1}{30{\cdot}65}$	63·85	0·04035
31·39	8·85	$\frac{1}{34{\cdot}68}$	63·83	0·03560
34·92	8·85	$\frac{1}{39{\cdot}10}$	63·65	0·03162
40·54	8·75	$\frac{1}{46{\cdot}37}$	63·64	0·02665
46·56	8·97	$\frac{1}{54{\cdot}61}$	63·68	0·02264
54·33	8·99	$\frac{1}{66{\cdot}05}$	63·57	0·01871
64·96	9·05	$\frac{1}{83{\cdot}53}$	63·74	0·01480
81·11	9·13	$\frac{1}{114{\cdot}2}$	63·75	0·01083
106·88	9·20	$\frac{1}{186{\cdot}0}$	63·75	0·00665
145·54	9·25	$\frac{1}{327{\cdot}6}$	63·70	0·00377
222·92	9·22	$\frac{1}{447{\cdot}0}$	63·82	0·00277

TABLE III.—Compressibility of Carbonic Acid Gas.—99°·5–100°·7.

p.	t.	ϵ.	t'.	θ.
17·42	5°·83	$\frac{1}{18\cdot01}$	100°·39	0·07628
20·17	6·04	$\frac{1}{20\cdot97}$	100·37	0 06543
22·37	6·01	$\frac{1}{23\cdot34}$	100·41	0·05880
24·85	6·00	$\frac{1}{26\cdot07}$	100·72	0·05269
27·76	5·83	$\frac{1}{29\cdot30}$	100·65	0·04687
31·06	5·88	$\frac{1}{33\cdot03}$	100·64	0·04158
34·57	5·92	$\frac{1}{37\cdot06}$	100·62	0·03705
40·09	5·94	$\frac{1}{43\cdot50}$	100·60	0·03156
45·99	6·31	$\frac{1}{50\cdot60}$	100·37	0·02712
53·81	6·34	$\frac{1}{60\cdot26}$	100·33	0·02277
64·27	6·34	$\frac{1}{73\cdot89}$	100·37	0·01857
80·25	6·35	$\frac{1}{96\cdot52}$	100·37	0·01422
105·69	6·36	$\frac{1}{137\cdot3}$	100·37	0·01000
145·44	8·73	$\frac{1}{219\cdot0}$	99·46	0·00625
223·57	8·72	$\frac{1}{380\cdot3}$	99·44	0·00359

Before discussing these results on the compressibility of carbonic acid, it will be convenient to have accurate data for reducing the experiments in each table to the same temperature. These data will be supplied when the coefficients of expansion of carbonic acid under varied pressures and at different parts of the thermometric scale are known. The determination of these coefficients will form the subject of the next section.

§ II.

In the limiting case of the so-called perfect gas, which is closely approximated to but probably never actually realized in nature, the change of volume under a constant pressure would for the same range of temperature correspond exactly to the change of elastic force under a constant volume[*]. In the case of carbonic acid, REGNAULT has shown that, even at low pressures, there is a marked difference in the value of α as given by the two methods; and from the experiments I am about to describe, it will appear that at high pressures the results diverge so widely that they must not in any way be confounded with one another. For the sake of precision, I propose to designate by α the coefficient of expansion for change of temperature under a constant pressure, and by α' the coefficient of elastic force for change of temperature under a constant volume. We shall confine our attention in this section to the determination of the values of α under varied pressures and at different parts of the thermal scale.

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[*] According to RUDBERG the coefficient of expansion of air between 0° and 100°, deduced from the two methods, is precisely the same; according to REGNAULT there is an actual difference of $\frac{1}{733}$ part of the whole coefficient (POGGENDORFF's 'Annalen,' vol. xliv. p. 122; Mém. de l'Acad. des Sciences, vol. xxi. p. 119).

In the next table the results are given of a set of experiments I have made to determine the *average* coefficient of expansion for heat of carbonic acid from 0° to about 7°·5 under pressures varying from 12 to 34·5 atmospheres. For this range of temperature the pressures could not be carried higher, on account of the liquefaction of the gas. In this table p is the pressure as indicated by the air-manometer, t the temperature of the manometer, and v' the volume in cubic centimetres of the carbonic acid at the pressure p and temperature t'.

TABLE IV.—Values of α from 0° to 7°·5.—Constant Pressure.

p.	t.	v'.	t'.	α.
12·02	7·53°	0·07298	7·54°	0·00462
12·00	6·73	0·07065	0·00	
16·22	7·65	0·05243	7·64	0·00520
16·25	6·65	0·05031	0·00	
20·10	7·61	0·04108	7·63	0·00607
20·09	6·64	0·03928	0·00	
24·81	7·63	0·03192	7·64	0·00700
24·80	6·64	0·03031	0·00	
27·70	7·44	0·02775	7·45	0·00782
27·66	6·47	0·02627	0·00	
31·07	7·65	0·02386	7·65	0·00895
31·06	6·64	0·02234	0·00	
34·49	7·45	0·02058	7·46	0·01097
34·48	6·64	0·01903	0·00	

In calculating the values of α in the foregoing table, the observed volume (v') of the carbonic acid at the higher temperature (7°·54 &c.) was in each case corrected for the small differences of pressure which occurred in the observations at that temperature and at 0°. In many cases it would have been sufficient to make this correction by BOYLE'S law; but the exact data for the purpose being supplied by Tables I., II., and III., I have in these and other similar cases always employed the direct results given by experiment of the compressibility of carbonic acid at the pressures and temperatures indicated.

In the two following tables the values of α are calculated from the results in Tables I., II., and III., the value of θ in Table I. having been first reduced to 0° by means of the coefficients at the respective pressures given in Table IV.

TABLE V.—Values of α from 0° to 64°.—Constant Pressure.

p.	t'.	θ.	α.
17·09	0°·00 63·86	0·05190 0·06892	0·005136
20·10	0·00 63·76	0·04280 0·05790	0·005533
22·26	0·00 63·79	0·03785 0·05188	0·005811
24·81	0·00 63·77	0·03306 0·04614	0·006204
27·69	0·00 63·85	0·02864 0·04096	0·006737
31·06	0·00 63·83	0·02444 0·03603	0·007429
34·49	0·00 63·65	0·02086 0·03208	0·008450

TABLE VI.—Values of α from 0° to 100°.—Constant Pressure.

p.	t'.	θ.	α.
17·09	0°·00 100·39	0·05190 0·07792	0·004994
20·10	0·00 100·37	0·04280 0·06567	0·005324
22·26	0·00 100·11	0·03785 0·05906	0·005597
24·81	0·00 100·72	0·03306 0·05278	0·005922
27·69	0·00 100·65	0·02864 0·04700	0·006369
31·06	0·00 100·64	0·02444 0·04158	0·006968
34·49	0·00 100·62	0·02086 0·03715	0·007762*

* By an entirely different method REGNAULT has examined the expansion by heat of carbonic acid gas between 0° and 100° for pressures varying from 1 to 15·6 atmospheres. As his results form a consecutive series with those of Table VI. I subjoin them. It must be remembered that p represents here true pressures in atmospheres.

p.	α.
1·00	0·003710
3·32	0·003845
5·64	0·004006
9·17	0·004227
11·27	0·004408
15·61	0·004858

(Mém. de l'Acad. des Sciences, vol. xxi. p. 117, and vol. xxvi. p. 575.)

From Tables V. and VI. it is easy to calculate the values of α from 64° to 100° referred to the unit volume at 0°. These values will be found in the fourth column of the next table, and for comparison the values of α at the corresponding pressures from 0° to 7°·5, and from 0° to 64°, have been taken directly from the same tables.

Table VII.—Values of α at different temperatures.—Constant Pressure.

p.	α.		
	0°–7°·5.	0°–64°.	64°–100°.
17·09	......	0·005136	0·004747
20·10	0·00607	0·005533	0·004958
22·26	....	0·005811	0·005223
24·81	0·00700	0·006204	0·005435
27·69	0·00782	0·006737	0·005730
31·06	0·00895	0·007429	0·006169
34·49	0·01097	0·008450	0·006574

It has hitherto been assumed, but without direct experimental proof, that matter in the gaseous state will expand for every degree through which it is heated by the same fraction of its volume at 0°, provided the pressure remains constant. This important law, which is due to Gay-Lussac, is unquestionably true in the case of the perfect (ideal) gas; and in the case of air and other gases which have not been liquefied, it may be employed for all practical purposes without sensible error. But, as far as I have been able to discover, no experiments have hitherto been published to determine under what limitations it applies to the gaseous state as that state is presented to us in nature*. It will be evident from a cursory inspection of Table VII. that this law does not hold good in the case of carbonic acid gas even at moderate pressures, and that the divergence from the law becomes greater as the pressure is increased. Thus under a pressure of 20·1 atmospheres the coefficients of expansion, referred to the same unit, between 0° and 7°·5, 0° and 64°, and 64° and 100° respectively, are in the ratio of the numbers

1·000, 0·911, 0·817;

and under a pressure of 34·49 atmospheres the corresponding ratios for the same ranges of temperature are

1·000, 0·770, 0·599.

It is scarcely necessary to add that if the law of Gay-Lussac held good, the coefficients in all these cases would have been the same, and their ratios expressed by 1·000. I have not made any comparative experiments at pressures lower than 17 atmospheres; but there can be no doubt that, even at the ordinary pressure of the atmosphere, carbonic acid gas will diverge sensibly from GAY-LUSSAC's law, and that its coefficient of expansion under constant pressure will change with the temperature, being less at high than at low temperatures.

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* Biot states, indeed, somewhat vaguely, that Gay-Lussac verified this law experimentally for air and other gases and found it to be strictly true; but the experiments themselves have never been published, and the methods of investigation employed by Gay-Lussac are now known to have been imperfect, so that they failed even to show the differences in the dilatation by heat of different gases (Biot, 'Traité de Physique,' vol. i. p. 188). The experiments of Regnault on the comparative march of the air and carbonic acid thermometer, to which I shall have occasion hereafter to refer, were made by observing the change of elastic force under a constant volume. Regnault states expressly that he made no corresponding experiments under constant pressure (Mém. de l'Acad. des Sciences, vol. xxi. pp. 168–171).

It follows from these observations that the coefficients of expansion in the foregoing tables are the average coefficients for the ranges of temperature to which they apply. It would not be difficult from the experimental results to obtain an empirical formula which would give approximately the coefficient or rate of expansion, at any temperature and under any pressure, within the range of the experiments, so as to construct tables showing the expansion by heat of carbonic acid under different pressures. But I have refrained from doing so, as such a table would seldom be required in practice; and for scientific purposes, as I have had occasion in the course of this inquiry more than once to observe, the results of empirical formulæ are apt to mislead the investigator and rarely aid research.

For the same temperature, the coefficient of expansion increases as the pressure augments, and more rapidly at low than at high temperatures. In the preceding tables, the pressures, being always referred to the unit volume at 0°, could not be carried beyond 34·5 atmospheres. In the next table the coefficient of expansion for heat of carbonic acid gas, referred to the unit volume at 64°, is given at pressures ranging from 17 to 223 atmospheres.

TABLE VIII.—Values of α from 64° to 100°.—Constant Pressure. Volume at 64°=1.

p.	t'.	θ.	α.
17·09	63°·86 100·39	0·06892 0·07792	0·003572
20·10	63·76 100·37	0·05790 0·06567	0·003657
22·26	63·79 100·11	0·05188 0·05906	0·003808
24·81	63 77 100·72	0·04614 0·05278	0·003892
27·69	63·85 100·65	0·04096 0·04700	0·004008
31·06	63·83 100·64	0·03603 0·04158	0·004187
34·49	63·65 100·62	0·03208 0·03715	0·004266
40·54	63·64 100·60	0·02665 0·03118	0·004596
46·54	63·68 100·37	0·02264 0·02676	0·004946

TABLE VIII. (continued).

p.	t.	θ.	α.
54·33	63°·57	0·01871	0·005535
	100·33	0·02252	
64·96	63·74	0·01480	0·006512
	100·37	0·01833	
81·11	63·75	0·01083	0·008033
	100·37	0·01402	
106·9	63·75	0·00665	0·013150
	100·37	0·00986	
145·5	63·70	0·00377	0·018222
	99·62	0·00625	
223·0	63·82	0·00277	0·008402
	99·44	0·00360	

The coefficient of expansion, it will be observed, steadily increases with the pressure, till at 145·5 atmospheres it has reached the large value of 0·01822. But as the pressure is further augmented, the coefficient, instead of continuing to increase, begins to diminish; and at 223 atmospheres it has actually fallen to 0·008402, or to less than one half its value at 145 atmospheres. This change of direction in the value of the coefficient is easily explained, if we observe that carbonic acid at 64° has entered, under these high pressures, into those intermediate conditions which form the link between the gaseous and liquid states of matter. It has, in short, at 223 atmospheres, approached the liquid volume without liquefying, and its coefficient begins to change to that which belongs to the liquid state. We shall find in the course of this inquiry abundant proofs of the accuracy of this statement.

§ III.

We now proceed to consider the change in the elastic force of a gas when, the volume being maintained constant, the temperature is altered. As in the expansion of a gas under constant pressure, we have here two distinct questions to consider, both of which are highly important in reference to the laws of molecular action. The first question is the effect of increase of pressure on the value of the coefficient; the second, the change, if any, of the coefficient for different parts of the thermal scale. The apparatus required no modification whatever for these experiments; but in making the adjustments for constant volume, the change of volume of the glass tube must be carefully allowed for, as the same reading by the cathetometer will not correspond to the same volume at different temperatures. The correction was always made by the equation given before,

$$c_{t'}=c_0(1+\tfrac{2}{3}kt').$$

As I have already mentioned, the coefficient of elastic force under constant volume will be designated by α', to distinguish it from α the coefficient of expansion under constant pressure. In the following tables the letters p, t, and t' have the same signification as before, but instead of θ, the actual volumes, in fractions of a cubic centimetre, of the carbonic acid are given in the column designated CO_2. In calculating the coefficients, a slight correction had to be applied to the observed pressures when the volume of the carbonic acid was not precisely the same at the corresponding observations.

Table IX.—Values of α' from 0° to 6°·5.—Constant Volume.

p.	t.	CO_2.	t'.	α'.
21·48	7°·27	0·03623	0°·00	0·00537
22·18	6·08	0·03623	6·07	
25·87	7·17	0·02867	0·00	0·00588
26·86	6·51	0·02867	6·51	
33·53	7·27	0·01983	0·00	0·00734
35·13	6·51	0·01983	6·50	

Table X.—Values of α' from 0° to 64°.—Constant Volume.

p.	t.	CO_2.	t'.	α'.
16·42	7°·29	0·04969	0°·00	0·004754
21·42	3·68	0·04968	64·00	
21·48	7·27	0·03623	0·00	0·005237
28·65	3·69	0·03624	63·80	
25·87	7·17	0·02867	0·00	0·005728
35·29	3·70	0·02869	63·74	
30·37	6·75	0·02304	0·00	0·006357
42·74	3·27	0·02303	63·98	
33·53	7·27	0·01983	0·00	0·006973
48·40	3·36	0·01986	63·94	

Table XI.—Values of α' from 0° to 100°.—Constant Volume.

p.	t.	CO_2.	t'.	α'.
16·42	7°·29	0·04969	0°·00	0·004700
24·19	3·70	0·04969	100·67	
21·48	7·27	0·03623	0·00	0·005138
32·60	3·70	0·03622	100·67	
25·87	7·17	0·02867	0·00	0·005610
40·44	3·73	0·02870	100·67	
30·37	6·75	0·02304	0·00	0·006177
49·25	3·65	0·02303	100·54	
33·53	7·27	0·01983	0·00	0·006741
56·16	3·64	0·01986	100·48	

From Tables X. and XI. the values of α' from 64° to 100° referred to the unit pressure at 0° are easily calculated. In the next table the values of α' at the different parts of the thermal scale are given, p being the initial pressure in each case.

TABLE XII.—Values of α' at different temperatures.—Constant Volume.

p.	α'.		
	0°–6°·5.	0°–64°.	64°–100°.
16·42	....	0·004754	0·004607
21·48	0·00537	0·005237	0·004966
25·87	0·00588	0·005728	0·005406
30·37	....	0·006357	0·005861
33·53	0·00734	0·006973	0·006334

It follows from this investigation that the value of α' is greater at high than at low pressures; it changes also with the temperature, the pressure remaining constant, being less at high than at low temperatures. The values are, for this reason, average values for each range of temperature. The law of GAY-LUSSAC, therefore, fails both in the case of α and of α'; that is to say, *the dilatation by heat of a body in the ordinary gaseous state, whether measured by its expansion under constant pressure or by the increase of elastic force under constant volume, is not a simple function of the initial volume or initial elastic force, but a complex function changing with the temperature**.

In the next Table will be found the change in the value of α' between 64° and 100° under a large range of pressure and referred to the pressure at 64° as unit.

TABLE XIII.—Values of α' from 64° to 100°.—Constant Volume. Pressure at 64°=1.

p.	t'.	CO_2.	α'.
21·42	64·00	0·04968	0·003526
24·19	100·67	0·04969	
28·65	63·80	0·03624	0·003718
32·60	100·67	0·03622	
35·29	63·74	0·02869	0·003956
40·44	100·67	0·02870	
42·74	63·98	0·02303	0·004166
49·25	100·54	0·02303	
48·40	63·94	0·01986	0·004387
56·16	100·48	0·01986	
67·65	63·80	0·01288	0·005392
80·99	100·50	0·01289	
94·27	63·78	0·00778	0·007018
118·60	100·50	0·00778	

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* The statement of REGNAULT that the air and carbonic acid thermometers march sensibly together appears to be at variance with this conclusion. But REGNAULT's own experiments, which were made at pressures differing little from that of the atmosphere, indicate an unequivocal although small difference, and in the right direction, between the two thermometers. With a sulphurous acid thermometer the difference was considerable, and in conformity with the result stated in the text (Mém. de l'Acad. des Sciences, vol. xxi. pp. 187–88).

§ IV.

We are now prepared for the discussion of the general results of this investigation. For this purpose it will be convenient to reduce the values of ε as given in Tables I., II., and III. to the exact temperatures of 6°·5, 64°, and 100° respectively. The differences between the temperatures (t') at which the observations were made and these numbers are so small that the reductions presented no difficulty with the data furnished in § II. In the last column of the three following tables will be found the values of ρ as given by the equation

$$\rho=\varepsilon p.$$

Table XIV.—Values of ρ at 6°·5.

p.	t'.	ε.	ρ.
12·01	6°·5	$\frac{1}{12·95}$	0·9274
13·22	6·5	$\frac{1}{14·37}$	0·9200
14·68	6·5	$\frac{1}{16·13}$	0·9101
17·09	6·5	$\frac{1}{19·12}$	0·8938
20·10	6·5	$\frac{1}{23·03}$	0·8728
22·26	6·5	$\frac{1}{25·96}$	0·8575
24·81	6·5	$\frac{1}{29·62}$	0·8376
27·69	6·5	$\frac{1}{34·03}$	0·8137
31·06	6·5	$\frac{1}{39·59}$	0·7845
34·49	6·5	$\frac{1}{45·80}$	0·7530

TABLE XV.—Values of ρ at 64°.

p.	t'.	ε.	ρ.
17·60	64°	$\frac{1}{18\cdot57}$	0·9478
20·36	64	$\frac{1}{21\cdot65}$	0·9404
22·56	64	$\frac{1}{24\cdot18}$	0·9330
25·06	64	$\frac{1}{27\cdot08}$	0·9254
28·07	64	$\frac{1}{30\cdot64}$	0·9161
31·39	64	$\frac{1}{34\cdot67}$	0·9054
34·92	64	$\frac{1}{39\cdot08}$	0·8935
40·54	64	$\frac{1}{46\cdot34}$	0·8748
46·56	64	$\frac{1}{54\cdot57}$	0·8532
54·33	64	$\frac{1}{65\cdot97}$	0·8235
64·96	64	$\frac{1}{83\cdot44}$	0·7785
81·11	64	$\frac{1}{114\cdot0}$	0·7115
106·88	64	$\frac{1}{185\cdot5}$	0·5762
145·54	64	$\frac{1}{325\cdot9}$	0·4466
222·92	64	$\frac{1}{446\cdot4}$	0·4994

TABLE XVI.—Values of ρ at 100°.

p.	t'.	ε.	ρ.
20·17	100°	$\frac{1}{20\cdot98}$	0·9614
22·37	100	$\frac{1}{23\cdot35}$	0·9580
24·85	100	$\frac{1}{26\cdot09}$	0·9525
27·76	100	$\frac{1}{29\cdot32}$	0·9468
31·06	100	$\frac{1}{33\cdot05}$	0·9398
34·57	100	$\frac{1}{37\cdot09}$	0·9320
40·09	100	$\frac{1}{43\cdot54}$	0·9208
45·99	100	$\frac{1}{50\cdot63}$	0·9083
53·81	100	$\frac{1}{60\cdot30}$	0·8924
64·27	100	$\frac{1}{73\cdot97}$	0·8689
80·25	100	$\frac{1}{96\cdot65}$	0·8303
105·69	100	$\frac{1}{137\cdot6}$	0·7681
145·44	100	$\frac{1}{218\cdot0}$	0·6671
223·57	100	$\frac{1}{379\cdot3}$	0·5894

From the results given in the last three tables, it is manifest that the values of ρ, which in the case of a perfect (ideal) gas would always be unit, steadily diminish for the same temperature as the pressure increases. An important exception to this remark occurs in the last recorded result in Table XV., from which it appears that at the temperature of 64° the value of ρ, which had diminished from 0·9478 to 0·4466 as the pressure was raised from 17·6 to 145·5 atmospheres, instead of continuing to diminish with a further increase of pressure, actually changes its direction, and at 223 atmospheres has increased to 0·4994. No change of this kind occurs at 100°, although the experiments were carried to 224 atmospheres. The explanation of this change in the value of ρ, after a certain pressure has been reached, I have already anticipated when referring to a similar change in the coefficient of expansion by heat at high pressures, as shown in Table VIII. At the temperature of 64°, and under a pressure of 223 atmospheres, carbonic acid has in fact approached the liquid volume, while passing through those intermediate conditions of matter which, in a former Bakerian Lecture, I have described as establishing an unbroken continuity between the ordinary gaseous and ordinary liquid states. At 100° carbonic acid under the same external pressure has not reached this stage of the process; but if the experiment had been carried to higher pressures, a like change in the value of ρ would no doubt have occurred. These remarks will be fully confirmed when I give the values of ρ for the gaseous and liquid states at the same temperature, as calculated from my former experiments*. The true import of the values of ρ at a constant temperature will be considered hereafter.

From Tables XIV., XV., and XVI. it further appears that the values of ρ approach more nearly to unit the higher the temperature, in accordance with the principle I deduced from my former experiments, that as the temperature becomes higher the curves representing the change of volume of carbonic acid at different pressures approach more nearly to the curve of a perfect gas. But to find the actual relation which exists between these curves it will be necessary to make a preliminary calculation.

In the curves representing the changes of volume of a gas by pressure at different temperatures, I propose to designate those points where the values of ρ are equal, homologues, or homologous points, and the lines passing through corresponding homologues, homologous lines. Let μ be the ratio between the external pressures p and p' at homologous points on the curves of any two temperatures, or

$$\mu=\frac{p}{p'}.$$

In Tables XVII. and XVIII. the values of μ are calculated for the respective temperatures of 6°·5 and 64°, and of 64° and 100°, from the values of ρ in the preceding tables. The necessary reductions to obtain the homologous points at each temperature were carefully made.

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* Philosophical Transactions for 1869, p. 581.

TABLE XVII.—Values of μ for 6°·5 and 64°.

ρ.	p (6°·5).	p'(64°).	μ.
0·9254	12·31	25·06	0·491
0·9161	13·79	28·07	0·491
0·9054	15·39	31·39	0·490
0·8935	17·13	34·92	0·491
0·8748	19·81	40·54	0·489
0·8532	22·83	46·56	0·490
0·8235	26·51	54·33	0·488
0·7785	31·73	64·96	0·489

From the foregoing table it appears that the values of μ within the limits of pressure employed are always equal—that is to say, *the ratio of the external pressures is always the same for homologous points of the curves of* 6°·5 and 64°. The experiments could not be carried to higher pressures on account of the liquefaction of the gas at 6°·5. In the next table the values of μ for the homologues of 64° and 100° are given.

TABLE XVIII.—Values of μ for 64° and 100°.

ρ.	p (64°).	p' (100°).	μ.
0·9404	20·36	30·79	0·661
0·9330	22·56	34·10	0·662
0·9254	25·06	37·88	0·662
0·9161	28·07	42·37	0·662
0·9054	31·39	47·39	0·662
0·8935	34·92	53·29	0·655
0·8748	40·54	61·76	0·656
0·8532	46·56	70·95	0·656
0·8235	54·33	83·04	0·654
0·7785	64·96	101·53	0·640
0·7115	81·11	127·96	0·634
0·5762	106·80	236·84	0·451

The values of μ are again equal till very high pressures are reached. Thus from 20·4 to 31·4 atmospheres, and from 30·8 to 47·4 atmospheres, the agreement is absolute; after which a slight diminution in the value of μ occurs, but only to the amount of $\frac{1}{90}$ of the whole, till the respective pressures of 54·3 and 83·0 atmospheres are attained. Even at 81·1 and 128·0 atmospheres the value of μ has only fallen from 0·661 to 0·634. But at still higher pressures we reach a new phase, and at the respective pressures of 107 and 237 atmospheres the value of μ has fallen to 0·451.

I have calculated the values of ρ and μ from the experiments at lower temperatures in my former communication[*]. As these experiments were chiefly made at temperatures not much above the critical point of carbonic acid, when the intermediate conditions of matter corresponding to the fall from the gaseous to the liquid state, and those corresponding to the liquid state itself, are easily recognized, they form a valuable complement to the foregoing.

[*] Philosophical Transactions for 1869, pp. 584–86.

Table XIX.—Values of ρ at 31°·1, 35°·5, and 48°·1.

31°·1.		35°·5.		48°·1.	
p.	ρ.	p.	ρ.	p.	ρ.
54·79	0·6802	56·80	0·6866	62·60	0·7241
55·96	0·6710	59·34	0·6672	68·46	0·6888
57·18	0·6604	62·15	0·6446	75·58	0·6416
58·46	0·6493	65·23	0·6154	84·35	0·5746
59·77	0·6368	68·66	0·5799	95·19	0·4795
61·18	0·6238	72·45	0·5363	109·40	0·3666
62·67	0·6078	76·58	0·4751		
64·27	0·5864	81·28	0·3565		
65·90	0·5671	86·60	0·2461		
67·60	0·5434	89·52	0·2395		
69·39	0·5159	92·64	0·2388		
71·25	0·4821	99·57	0·2423		
73·26	0·4335	107·60	0·2501		
73·83	0 4233				
75·40	0·2424				
77·64	0·2103				
79·92	0·2087				
82·44	0·2083				
85·19	0·2101				

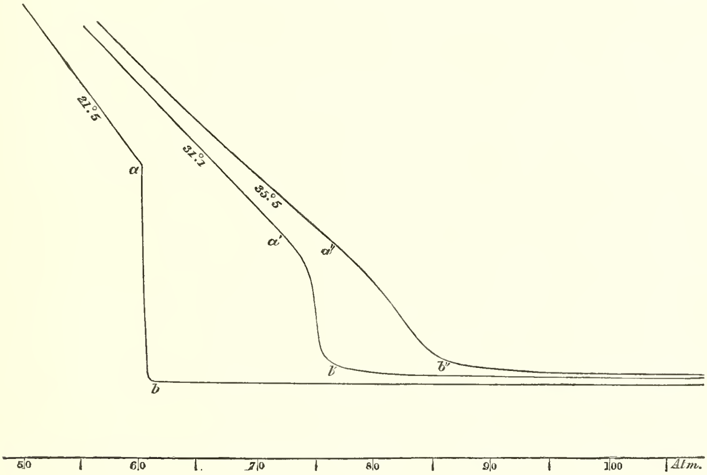
Table XX.—Values of μ for 31°·1 and 48°·1.

ρ.	p (31°·1).	p' (48°·1).	μ.
0·6802	54·79	69·81	0·785
0·6710	55·96	71·26	0·785
0·6604	57·18	72·93	0·784
0·6493	58·46	74·51	0·785
0·6368	59·77	76·25	0·784
0·6238	61·18	78·06	0·784
0·6078	62·68	80·00	0·784
0·5864	64·27	82·81	0·777
0·5671	65·90	85·20	0·773
0·5434	67·60	87·91	0·769
0·5159	69·39	91·04	0·762
0·4821	71·25	94·90	0·751
0·4335	73·26	100·98	0·726
0·4233	73·83	102·26	0·722
0·2424	75·40	125·00	0·603

Table XXI.—Values of μ for 35°·5 and 48°·1.

ρ.	p (35°·5).	p' (48°·1).	μ.
0·6866	56·80	68·81	0·826
0·6672	59·34	71·86	0·826
0·6446	62·15	75·16	0·827
0·6154	65·23	79·22	0·824
0·5799	68·66	83·71	0·820
0·5363	72·45	88·98	0·814
0·4751	76·58	95·72	0·800

These results, calculated from experiments published seven years ago, are in complete accordance with the conclusions I have deduced from the present investigation. On comparing the pressures with the graphic representation given in the paper referred to, it will be seen that, so long as the values of μ are equal, the carbonic acid is in the gaseous state proper at the lower as well as at the higher temperature; but when they undergo a marked diminution, the carbonic acid has entered into the intermediate conditions corresponding at lower temperatures to the fall to the liquid state. Finally, when the liquid volume has been attained, the value of ρ itself changes its direction, as may be seen in the results of the final experiments at 64°, 31°·1, and 35°·5 (Tables XV. and XIX.). In the annexed sketch the portions of the curves above a, a', a'' are in the gaseous state; from a to b we have in the curve for 21°·5 the fall from the gaseous to the liquid state; and from a' to b' and a'' to b'', in the curves for 31°·1 and 35°·5, the intermediate conditions between the gaseous state and liquid volume corresponding to the fall to the liquid state at lower temperatures. As in a gas below the critical temperature we have, (1) the gaseous state, (2) the fall to the liquid, and (3) the liquid state, so in a gas above the critical temperature we have, (1) the gaseous state, (2) the intermediate conditions corresponding to the fall, and (3) the conditions corresponding to the liquid volume. The first or gaseous state is characterized by the external pressures for homologous points at any two given temperatures being always in the same ratio to



one another; in the second state, or state of change corresponding to the fall to the liquid, this ratio changes rapidly; while in the third, or, as we may designate it, the liquid-volume state, new molecular conditions supervene, as shown by the increase in the value of ρ.

As the result of the foregoing investigation, the relations between pressure and volume in the *ordinary gaseous* state at different temperatures may be stated in the following terms:—

On any two isothermal curves which show the volume of carbonic acid gas under change of pressure at definite temperatures, the values of ρ at the homologous points being always equal, or

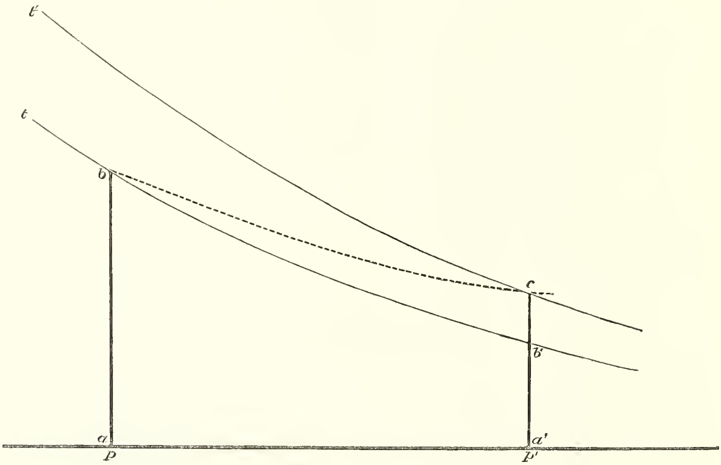
$$pv=p'v' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(A)}$$

(where, it must be carefully observed, v and v' are the volumes of the gas on different isothermals), it has been shown that for all such homologous points on any two isothermals

$$\frac{p}{p'}=\mu \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(B)}$$

where μ is a constant.

The full import of homologous points will be further understood from the following considerations:—Let the line $a\,b$ represent a volume of carbonic acid gas at the temperature t and pressure p, and let the pressure be increased to p', the new volume $a'\,b'$ of the gas will be less than $a\,b\frac{p}{p'}$. Let the gas be now heated at the pressure p' till its



volume $a'c$ is equal to $ab\frac{p}{p'}$, and let the temperature be now t'; the point c on the isothermal t' will be the homologue of the point b on the isothermal t. If the gas from p to p' had diminished in volume as a perfect gas, c would have been a point on the isothermal t. In short, the homologue c, of the point b on the isothermal t, is a point on the isothermal t' at which the action of the internal forces, in reducing the volume of the gas when the external pressure is increased from p to p', is exactly counterbalanced by the action of the expansive forces in heating the gas from t to t'.

By means of equations (A) and (B), if we know the relations of pressure and volume for a gas at any one temperature, we can, by the observation of a homologue at any other temperature, calculate the volume corresponding to all pressures at the second temperature. Thus the whole relations of volume and pressure in the case of a gas can be discovered from a set of primary observations at one fixed temperature, and the determination of a single homologue at each of the other temperatures.

We have now to inquire into the relations between the pressure and volume in the case of a gas at a constant temperature; in other words, to discover, if possible, the character of the primary curve from which, as we have seen, by means of the homologues, the curves of other temperatures may be traced. For this purpose we must find the values of $1-\rho$ from Tables XIV., XV., and XVI., and thence calculate the values of $\varepsilon(1-\rho)$ as given in the fourth column of the following tables.

Table XXII.—Values of $\varepsilon(1-\rho)$ at 6°·5.

p.	ε.	t'.	$1-\rho$.	$\varepsilon(1-\rho)$.
12·01	$\frac{1}{12·95}$	6°·5	0·0726	0·00561
13·22	$\frac{1}{14·37}$	6·5	0·0800	0·00557
14·68	$\frac{1}{16·13}$	6·5	0·0899	0·00557
17·09	$\frac{1}{19·12}$	6·5	0·1062	0·00555
20·10	$\frac{1}{23·03}$	6·5	0·1272	0·00552
22·26	$\frac{1}{25·96}$	6·5	0·1425	0·00549
24·81	$\frac{1}{29·62}$	6·5	0·1624	0·00549
27·69	$\frac{1}{34·03}$	6·5	0·1863	0·00547
31·06	$\frac{1}{39·59}$	6·5	0·2155	0·00544

TABLE XXIII.—Values of $\varepsilon(1-\rho)$ at 64°.

p.	ε.	t'.	$1-\rho$.	$\varepsilon(1-\rho)$.
17·60	$\frac{1}{18{\cdot}57}$	64°	0·0522	0·00281
20·36	$\frac{1}{21{\cdot}65}$	64	0·0596	0·00275
22·56	$\frac{1}{24{\cdot}18}$	64	0·0670	0·00277
25·06	$\frac{1}{27{\cdot}08}$	64	0·0746	0·00275
28·07	$\frac{1}{30{\cdot}64}$	64	0·0839	0·00274
31·39	$\frac{1}{34{\cdot}67}$	64	0·0946	0·00273
34·92	$\frac{1}{39{\cdot}08}$	64	0·1065	0·00273
40·54	$\frac{1}{46{\cdot}34}$	64	0·1252	0·00270
46·56	$\frac{1}{54{\cdot}57}$	64	0·1468	0·00269
54·33	$\frac{1}{65{\cdot}97}$	64	0·1765	0·00268
64·96	$\frac{1}{83{\cdot}44}$	64	0·2215	0·00266
81·11	$\frac{1}{114{\cdot}0}$	64	0·2885	0·00253
106·88	$\frac{1}{185{\cdot}5}$	64	0·4238	0·00228
145·54	$\frac{1}{325{\cdot}9}$	64	0·5534	0·00170
222·92	$\frac{1}{446{\cdot}4}$	64	0·5006	0·00112

TABLE XXIV.—Values of $\varepsilon(1-\rho)$ at 100°.

p.	ε.	t'.	$1-\rho$.	$\varepsilon(1-\rho)$.
20·17	$\frac{1}{20{\cdot}98}$	100°	0·0386	0·00184
22·37	$\frac{1}{23{\cdot}35}$	100	0·0420	0·00180
24·88	$\frac{1}{26{\cdot}09}$	100	0·0475	0·00182
27·76	$\frac{1}{29{\cdot}32}$	100	0·0532	0·00181
31·06	$\frac{1}{33{\cdot}05}$	100	0·0602	0·00182
34·57	$\frac{1}{37{\cdot}09}$	100	0·0680	0·00183
40·09	$\frac{1}{43{\cdot}54}$	100	0·0792	0·00182
45·99	$\frac{1}{50{\cdot}63}$	100	0·0917	0·00181
53·81	$\frac{1}{60{\cdot}30}$	100	0·1076	0·00178
64·27	$\frac{1}{73{\cdot}97}$	100	0·1311	0·00177
80·25	$\frac{1}{96{\cdot}65}$	100	0·1697	0·00176
105·69	$\frac{1}{137{\cdot}6}$	100	0·2319	0·00169
145·44	$\frac{1}{218{\cdot}0}$	100	0·3329	0·00152
223·57	$\frac{1}{379{\cdot}3}$	100	0·4106	0·00108

From these tables it is evident that the value of $\varepsilon(1-\rho)$ is constant so long as the carbonic acid is in the gaseous state, but that it rapidly diminishes when the gas passes into the intermediate conditions, till at high pressures it falls nearly as low as if the liquid had actually been formed. This will at once appear from the following short table, calculated from my former experiments at 13°·1, showing the values of $\varepsilon(1-\rho)$ in the gaseous and liquid states:—

TABLE XXV.—Values of $\varepsilon(1-\rho)$ at 13°·1.

p.	ε.	t'.	$1-\rho$.	$\varepsilon(1-\rho)$.
47·50	$\frac{1}{76\cdot16}$	13°·1	0·3763	0·00494
48·76	$\frac{1}{80\cdot43}$	13·1	0·3938	0·00490
48·89	$\frac{1}{80\cdot90}$	13·1	0·3957	0·00489
54·56	$\frac{1}{480\cdot4}$	13·1	0·8864	0·00184
75·61	$\frac{1}{500\cdot7}$	13·1	0·8490	0·00169
90·43	$\frac{1}{510\cdot7}$	13·1	0·8229	0·00161

From this investigation it follows that the relations of pressure and volume at a constant temperature for a body in the gaseous state is given by the equation

$$v(1-pv)=c \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad \text{(C)}$$

where p is the external pressure, v the volume of the gas, and c a constant.

From this equation the properties of homologous points already given in equations (A) and (B) follow as a direct consequence. For if

$$v(1-pv)=c$$

and

$$v'(1-p'v')=c'$$

be the equations of any two isothermals; then, since at homologous points $pv=p'v'$, we shall have

$$\frac{v'}{v}=\frac{c'}{c}$$

and

$$\frac{p}{p'}=\frac{c'}{c}=\mu.$$

If the values of $\varepsilon(1-\rho)$ in Tables XXII., XXIII., XXIV. are carefully examined, it will be seen that they have a slight tendency to diminish, particularly at the lower temperatures; and a similar observation applies to the values of μ in former tables. It must be remembered that the pressures recorded in these tables are those of the air-manometer, and would require a small correction to reduce them to true pressures. The data for making this correction are so imperfect, and for the higher pressures so uncertain, that I have not ventured to use them. According to Regnault, the indications of the air-manometer are $\frac{1}{83}$ too high at 20 atmospheres; according to Cailletet, they are $\frac{1}{80}$ too high at 60 atmospheres, and only $\frac{1}{1000}$ in error at 200 atmospheres. The application of these corrections would nearly remove in many cases the slight differences in the values of μ and of $\varepsilon(1-\rho)$; but I have thought it better to give only the direct results of experiment till the true corrections to be applied are accurately known.

Another disturbing cause must be noticed, of little importance under the conditions of the foregoing experiments, but one which would seriously derange the results if the experiments had been carried down to pressures of 2 or 3 atmospheres. In all the tables I have given it has been assumed that, under a pressure of one atmosphere, one volume of the carbonic acid gas corresponds to one atmosphere of pressure. This assumption is not strictly legitimate, as it was shown long ago by Von Wrede that the density of carbonic acid compared with air is slightly less at one fourth of an atmosphere than at one atmosphere. In the absence again of complete data I have not attempted to correct for this disturbing cause, particularly as its influence would be very small at the pressures recorded in this paper. I hope to be able to supply hereafter both deficiencies; but in the mean time it is certain that none of the general laws I have given will be disturbed by the application of the corrections referred to.

I will now make a few observations on the properties of the gaseous state of matter.

1. In the ideal, or, as it is commonly called, the perfect gaseous state, matter would obey implicitly the external forces which act upon it, the volume being always inversely as the forces externally applied. In this state it would neither offer resistance to change of volume*, nor, from the action of internal attractive forces, would it undergo a greater diminution of volume than that due to the external pressure. The characteristic property of this state is

$$\alpha=\alpha',$$

where α is the coefficient of expansion at constant pressure, and α' the coefficient of elastic force at constant volume. It has not been ascertained with certainty whether this condition of matter actually exists in nature, although, in gases which are at temperatures greatly above their critical points and at ordinary pressures, the deviation from it can only be discovered by the most exact experiments. Whether at higher temperatures or lower pressures the ideal condition is absolutely realized, or only indefinitely approached, is a question which will perhaps scarcely admit of a direct experimental solution.

2. In the gaseous state, as we observe it, there are two distinct causes of internal disturbance whose results are directly opposed, and, according to the nature of the gas and the conditions of pressure and temperature, sometimes the one and sometimes the other predominates. One of these disturbances is due to the action of internal forces tending

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* By resistance to change of volume is to be understood a resistance from internal causes whereby the gas undergoes a less diminution of volume under increased pressure than would occur in the case of an ideal gas obeying Boyle's law.

to produce a diminution of volume; the other is due to molecular conditions producing a resistance to diminution of volume other than that which occurs in a perfect gas. In the case of ordinary liquids the resistance to change of volume from increase of pressure is very great; in such liquids as liquid carbonic acid it is not so great, but it augments as the pressure is increased.

In the case of the permanent gases (or gases which have not hitherto been liquefied) the resistance to change of volume becomes predominant between 100 and 200 atmospheres, and at higher pressure it steadily increases. In hydrogen it appears under the lowest pressures at which that gas has been examined. It is probable, therefore, that this resistance to change of volume occurs in all gases even at low pressures, although, except in the case of hydrogen, it cannot be directly observed at low pressures, from the internal attractive forces producing a much greater change in the opposite direction. In the play of these opposing internal actions we have the explanation of the singular fact that the air-manometer indicates almost true pressures at 200 atmospheres, while at lower pressures its indications are above, and at higher pressures below the truth*. It is commonly assumed that in hydrogen gas the molecular forces producing internal attraction are absent; but this conclusion is doubtful, as the effects observed are probably here also differential. In carbonic acid, on the other hand, the internal attractive forces are very powerful, and mask the effects due to resistance to pressure till the gas is reduced to a small fraction of its volume under one atmosphere. In the experiments from which the laws of the ordinary gaseous state, as enunciated in equations (A), (B), and (C), were derived, I have always operated under the most favourable conditions for eliminating the influence of resistance to change of volume; and these laws are therefore to be regarded as characteristic of the gaseous state when the properties of the ideal gas are modified solely by the action of internal attractive forces.

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* Cailletet, 'Comptes Rendus,' vol. lxx. p. 1133.

XVIII. *The Minute Anatomy of the Alimentary Canal.* *By* HERBERT WATNEY, *M.A., M.D., Demonstrator of Microscopical Anatomy at St. George's Hospital. Communicated by Dr.* KLEIN, *F.R.S.*

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THE following is an account of a research undertaken in the laboratory of the Brown Institution in July 1873, under the direction of Dr. KLEIN, and carried on there under his direction until October 1874. During the last year it has been continued in the physiological laboratory of St. George's Hospital.

CHAPTER I.

THE MINUTE ANATOMY OF THE MUCOUS MEMBRANE OF THE INTESTINE, AND THE METHOD OF FAT-ABSORPTION.

In this chapter I propose first to state very briefly the result of my researches on the structure of the intestine and the method of fat-absorption; secondly, to relate the history of these subjects; and, finally, to give a detailed account of this research.

Preliminary Statement.

The mucous membrane of the intestine is pervaded everywhere by a reticulum similar to, and continuous with, that found in the follicles of PEYER'S *patches. This reticulum is situated among all the other elements which are contained in its meshes. This is true of the epithelial cells, the muscle-fibres, the cells of the parenchyma, and of the endothelial plates of the membrana propria, of the blood-vessels, and lymphatics.*

It is by this reticulum that the fat is absorbed, and by this reticulum that the fat finds its way into the lymphatic vessels, and probably also into the blood-vessels.

History.

ASSELIUS (1628) ascribed open mouths to the chyle-vessels of the intestine.

LIEBERKÜHN (1)*, HEWSON (2), and CRUIKSHANK (3) believed that the central canal of the villus opened on the surface. LIEBERKÜHN thought he saw one opening from the ampulla or widened end of the chyle-vessel. HEWSON conceived that the villi have a network of lacteals, and that the orifices of the lacteals are on the extremities of the villi. He considered it probable that the villi were erected "in order to make the small absorbents stand rigidly open;" and he thought that in this way the fluid (chyle) may be conveyed to the first pair of valves. CRUIKSHANK saw "in some hundred villi the trunk of a lacteal forming or beginning by radiated branches. The orifices of these radii were very distinct on the surface of the villus, as well as the radii themselves. The radii passing into the trunk of the lacteal were full of a white fluid. There was but one trunk in each villus."

RUDOLPHI (4), 1802, examined the villi of many animals; he denied the existence of openings of the chyle-vessel on the surface; he imagined that the chyle-vessels took their rise by a network within the villi.

FOHMAN (5), 1827, injected the lymphatics of fish with quicksilver. He found that no mercury escaped into the intestine, and concluded that the lymphatics end blindly.

After this there was a long contest as to the origin of the chyle-vessel and method of fat-absorption. We may distinguish three different opinions. The first was that the chyle-vessel arose from a network of lymph-capillaries: KRAUSE (6), GOODSIR (7), E. H. WEBER (8), NUHN (9), ZENKER (10). A second opinion maintained that the fat pressed through the villus, not in definite preformed ways, but among the parenchyma: FRERICHS (11), DONDERS (12), FUNKE (13), DÖNITZ (14). A third opinion was held by other observers, who maintained that the chyle-vessels are closed; they gave no opinion as to the manner in which fat traversed the villus: Henle (15), Schwann (16), Donders (12), Kölliker (44), and Bruch (18). Donders further spoke of the chyle-vessels as possessing a membrane.

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* See the References, p. 486.

Henle (15), 1837, showed that the intestine is covered by a layer of epithelium.

Goodsir (7), 1842, first noticed that the epithelial cells apparently contain fat-granules. He did not, however, lay any stress on the fact, but supposed that certain "vesicles" close to the membrane have the property of absorbing, and that the epithelium is cast off previous to absorption. This author saw the membrana propria clearly, and considered that the nuclei situated in it at regular distances were the germinal spots from which the epithelium is reproduced.

Lacauchie (19), 1843, first noticed the movements of the villi, and attributed them to a system of muscles. He considered each villus to be a system of sucking- and forcing-pumps (*aspirantes et foulantes*).

Gruby and Delafond (20), 1842 and 1843, found chyle in the epithelial cells, and thought that each epithelial cell must be considered an organ specially charged to receive raw chyle, and convert it to a homogeneous chyle, and to transmit the liquid thus made. Each epithelial cell is provided with a cavity whose external opening is sometimes gaping and at other times more or less exactly shut. They found that on the surface of the epithelium of the villi of the dog vibratile bodies exist, whose function may be to displace, when necessary, the raw chyle in contact with the epithelium. They independently discovered the movements of the villi.

E. H. Weber (8) noticed that the chyle-vessels were filled with chyle, although the mucosa was clothed with its epithelium; and no one after this seems to have doubted that the fat found its way through the epithelium, if we except Erdmann (34). Weber speaks of a second layer of cells which are round, some of which are filled with an opaque white fluid and some with a transparent fluid. He considered that the epithelium underwent a change in form in the act of absorption.

Frerichs (11), 1848, found that the granules of fat, which are of considerable size in the stomach, become finer in the intestine, this change being of a mechanical nature, probably caused by the action of bile, the pancreatic fluid, and the fluid of the intestine; he found that the fat thus finely divided presses gradually through the substance of the villus.

Funke (21), 1853, in his Atlas, gave a representation of the branched chyle-vessels (see fig. i. Taf. viii.).

Funke (13) afterwards (1855) spoke of the chyle-capillaries as being due to the fat pressing in everywhere in the tissue of the villus. He denied the existence of preformed ways.

Bruch (18), 1853, said that the fat enters the epithelial cells as little drops, which unite to form larger ones. He spoke of fat-absorption by the blood-vessels, and considered all the so-called branched chyle-vessels to be really blood-capillaries containing molecular fat; he included in that Funke's fig. i. Taf. viii.

VIRCHOW (22), 1853, noticed a white substance in the veins of the villi. He considered the whole parenchyma of the villus to be full of fat during absorption.

VIRCHOW (23), 1857, noticed that the epithelial cells of the gall-bladder are filled with fat, the fat lying in parallel rows in the epithelial cells.

BRÜCKE (24), 1851 and (25) 1853, repeated and confirmed the researches of LACAUCHIE, and of GRUBY and DELAFOND, concerning the contractility of the villi. BRÜCKE further showed that that contractility is due to bands of longitudinal muscle-fibres running up to the points of the villi; and, further, that these muscles are only processes from the muscularis mucosæ*. This author supposed that each epithelial cell is open at its distal and proximal ends, that the fat encounters (at the entrance to the cells) a plug of mucous consistence, and that the central canal is not a vessel but only a space between the tissue.

DONDERS (12), 1853 and 1856, denied the existence of openings at the ends of the epithelial cells. He thought that the fat goes through the villus in a cloud-like form.

MOLESCHOTT and MARFELS (26), 1854, maintained BRÜCKE'S opinion of the epithelial cells being open at their free extremities. They found that in frogs mammalian blood and in mammals pigment-granules penetrate the epithelium.

DONDERS, WITTICH (27), and HOLLANDER (28) obtained negative results on repeating the experiments of MOLESCHOTT and MARFELS.

KÖLLIKER (29) spoke in the most positive terms of the epithelial cells being closed at their free extremities; further, KÖLLIKER and FUNKE (30), 1855, showed that the "basal border" of the epithelium is striated. KÖLLIKER thought that the basal seam is penetrated by little pores through which the fat passes.

BRETTAUER and STEINACH (31), 1857, showed that the seam is sometimes composed of little rods.

There was much discussion, which may be found in the literature of the subject, on the character of the seam, its thickness in fat-absorption, and the manner in which fat penetrated it; and subsequently there was great dispute about the origin and significance of the goblet-cells. Neither of these questions will be entered upon in this paper.

TODD and BOWMAN (32), 1856, described a basement membrane in the villi as a single layer of homogeneous membrane.

This question of the existence of a basement membrane is nearly as important as the similar one of the occurrence of a membrane belonging to the chyle-vessels; for if there be a membrane, the views of HEIDENHAIN and all his followers must fall to the ground, unless we accept a basement membrane in the sense of KÖLLIKER. The following authors assert that there is a basement membrane:—GOODSIR (7), DONDERS (12), TODD and BOWMAN (32), EBERTH (33), DÖNITZ (14), ERDMANN (34), and DEBOVE (35).

BILLROTH (36), 1858, supposed that the epithelium of the frog's intestine has an intimate connexion with the connective-tissue corpuscles.

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* The muscularis mucosæ had been previously described by MIDDELDORPF in a paper on BRUNNER'S glands (1846).

HEIDENHAIN (37), 1858, put forward a definite theory of fat-absorption, namely, that the epithelial cells are in connexion with the branched cells of the parenchyma, that there is a direct transition of these cells into real chyle-vessels, and that these structures are preformed ways which the fat traverses. He gave drawings of nucleated epithelial cells ending in processes, the processes containing a second nucleus, and filled with fat (fig. iv.). HEIDENHAIN figured branched cells of the parenchyma connected with one another by processes (fig. vi.). In chromic acid, however, he found the cells were round and surrounded by a framework (fig. viii.).

This theory of the connexion of the epithelial cells with the connective-tissue corpuscles was afterwards supported by WIEGANDT (38), BALOGH (39), ARNSTEIN (40), EIMER (41), and THANHOFFER (57); but it was denied by RINDFLEISCH (42), LIPSKY (43), KÖLLIKER (44), VERSON (45), and BASCH (46). The connexion was necessarily denied by those who assumed an unbroken membrana propria, as DÖNITZ (14) and ERDMANN (34).

WIEGANDT (38), 1860, noticed the long processes attached to the epithelium of the frog's intestine; he could not find connective-tissue corpuscles with processes. WIEGANDT, however, considered HEIDENHAIN'S view to be probably correct for the epithelium of the frog.

BALOGH (39), 1860, described processes in the epithelium of the rabbit's intestine.

EBERTH (33), 1864, isolated the basement membrane which covers the villi. He found that the membrane has holes or gaps in it, and is attached to the blood-vessels (figs. i. & ii.). He described the membrana propria of LIEBERKÜHN'S crypts as a structureless membrane, with oval nuclei imbedded in it. EBERTH figured short processes to some of the epithelial cells (fig. ix.).

DÖNITZ (14), 1864, spoke of the fat coming in in the form of a cloud, and said that the epithelial cells with processes are artificial products. This author denied the presence of star-like or branching connective-tissue corpuscles in the mucosa; and maintained that the epithelium is separated from the parenchyma by a glass-like membrane containing no visible pores.

BASSLINGER (47), 1858, found that in birds the lymphatic follicles are not sharply bordered, but that the follicular tissue may be found in the base of the villi, or even extending to their apices.

HIS (48), 1862, showed that the tissue of the mucosa, including the villi, consists of a more or less close network of fine connective-tissue trabeculæ, or branched cells, which form a framework attached to the blood-vessels; in the meshes of the framework lymph-corpuscles are found. He called this tissue "adenoid." HIS further showed that lymphoid follicles are not formations of a peculiar kind, but are richer collections of adenoid substance. He gave a drawing of the tissue of a villus which had been brushed, in which the reticulum is clearly seen (see HIS, fig. iv.).

TEICHMAN (49), 1861, by his beautiful injections, showed the disposition of the chyle-vessels in the villi. He asserted that the chyle-vessels are closed.

RECKLINGHAUSEN (50), 1862, on the contrary, found that the material which he injected into the lymphatics of the villi left the vessel and passed into the stroma of the villus (see Taf. iii. fig. ii.). He showed that the walls of the chyle-vessels are lined by an endothelium. RECKLINGHAUSEN thought there was a Saftcanalsystem in the villi, although he allowed that there is a gradual transition from follicular tissue (adenoid tissue, HIS) to the Saftcanalsystem.

HIS (51) and AUERBACH (52) confirmed RECKLINGHAUSEN'S observation of the existence of an endothelial covering to the chyle-vessels. HIS maintained with TEICHMAN that the injection does not leave the chyle-vessels. Notwithstanding these researches, three observers, FLES (53), BASCH (54), and ZAWARYKIN (56), declared that in its upper part the central vessel has no definite membrane.

BASCH (54), 1865, found no difference between the cells of the villus and those lining the chyle-vessel. He injected from the lymphatics, and not only filled the central canal of the villus, but his injection penetrated the stroma of the villus in lines, forming a regular network.

LETZERICH (55), 1866 and 1867, described certain structures among the epithelial cells, which in the *normal* state are the sole absorbents of fat; these structures ("vacuoles") are connected with a system of canals, and the canals with the central vessel. In *pathological* states the epithelial cells contain fat. When not in action the vacuoles are closed, and are seen as star-shaped bodies between the epithelium. EIMER and other observers pointed out that the vacuoles are "goblet-cells."

KÖLLIKER (44), 1867, confirmed EBERTH'S researches as to the basement membrane. He held, however, that the border seam is nothing but a thickened outer layer of the connective tissue, corresponding to the border layer of the "follicular glands." KÖLLIKER considered it probable that the fat passes through the pores of the epithelial cells; and stated that the paths by which the fat travels in the tissue of the villus are unknown to anatomists.

ERDMANN (34), 1867, found that the epithelium is separated from the stroma of the villus by an unbroken membrane. This membrane sends processes, on the one hand, around the epithelial cells (as a cement substance), and, on the other hand, in the stroma of the villus (as connective-tissue trabeculæ)*. These trabeculæ enclose the connective-tissue corpuscles. The corpuscles of the villus are not star-like, but round; the fat travels by the cement substance between the epithelial cells.

EIMER (41), 1869, tried to demonstrate HEIDENHAIN'S theory. He gave drawings of the connexions of the epithelial cells with the tissue of the villus from sections of a hardened intestine of a frog†. EIMER further gave drawings of fat-particles in the processes of the branched connective-tissue corpuscles of the submucosa of the frog's intestine. These corpuscles are attached to the lymphatic vessels (figs. ix. & xiii.). This author found, during absorption, fat-particles in the circular muscular layer of the intestine. He figured fat-particles between the epithelial cells (fig. xx.). EIMER further considered that in mammals the epithelial cells are connected with the tissue of the villus.

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* FLES (1865) considered that the intercellular substance between the epithelial cells is in direct communication with the connective-tissue of the villus.

† Almost all the attempts to establish the connexions of the epithelial cells and the connective-tissue corpuscles have been made from preparations of the frog's intestine; and this is the more remarkable from the fact that the epithelial cells in that animal are very long and narrow, and that it is somewhat difficult to show their connexions.

ZAWARYKIN (56), 1869, obtained a natural injection of the paths which the chyle traverses by injecting albumen and Berlin blue into a loop of the intestine in the living animal. He found that the blue mass goes by the borders of the cells; these borders end in processes which communicate with the membrane of the villus. He found the substance of the villus coloured as it is represented by BASCH (54), *i. e.* he found a network of blue lines surrounding the lymph-corpuscles. ZAWARYKIN thought the blue lines correspond to the cleavage-spaces in the ground substance of the villus.

BASCH (46), 1870, described the villus as composed of trabeculæ and cells of the parenchyma; the trabeculæ contain connective-tissue corpuscles. The fat goes by ways within the trabeculæ which possibly are preformed. BASCH's drawings give very thick trabeculæ, containing cells (see his fig. vii.). He denied a constant connexion of the epithelium with the tissue of the villus. BASCH noticed the fat between the epithelial cells, but he conceived that it was due to regurgitation from the villus.

DEBOVE (35), 1872, showed by the use of nitrate of silver that there is everywhere in immediate proximity to the epithelium an endothelial membrane similar to that of the chyle-vessels.

THANHOFFER (57), 1874, found that the epithelial cells in the frog's intestine are open, that the cell-substance, in the form of hair-like processes, may protrude above the cells. This was seen when the nerve-centres were injured. These hair-like processes show lively movements, and aid in fat-absorption. He found star-like connective-tissue corpuscles attached to the epithelium.

Bibliography of the small Cells among the Epithelium.

EBERTH (58), 1861, found in the intestine of a duck groups of epithelial cells containing two to four nuclei, the nuclei lying one above the other.

RINDFLEISCH (42), 1861, found round elements among the deeper layers of the epithelial cells.

EBERTH (33), 1864, saw young cells among the intestinal epithelium; at times they were arranged in rows between the epithelial cells. He also saw citron-shaped cells. EBERTH was unable to determine whether these cells are young epithelial cells or not: he considered that some of them are elements which have wandered from the mucosa.

ARNSTEIN (40), 1867, found lymph-corpuscles between and within the individual epithelial cells; he found them also within the goblet-cells. He considered that these lymph-corpuscles have wandered from the mucosa.

FRIES (59), 1867, noticed the round cells among the intestinal epithelium.

EIMER (60), 1867, injected colouring-matter into the lymph-sac of a frog. He found coloured lymph-corpuscles in the goblet-cells and in the mucosa.

Lipsky (43), 1867, noticed small round cells in the epithelium covering Peyer's patches.

Verson (45), 1870, also mentions the occurrence of rounded cells between the attached extremities of the epithelial cells over Peyer's patches.

Methods employed.

Hardening in Chromic Acid.

The intestine or stomach of a recently killed animal was washed as soon as possible in one tenth per cent. chromic acid, or in one per cent. bichromate of potash, and then immediately transferred to chromic acid. After the chromic acid, it was placed in forty-six per cent. spirit and finally preserved in spirit of the strength of ninety-two per cent. (ordinary methylated spirit). To obtain a very firm tissue it was left from seven to ten days in one fifth per cent. chromic acid, and then from two to five days in the weaker spirit, before being transferred to the stronger.

To obtain sections which would show the lymph-corpuscles clearly differentiated from the other tissues, the stomach and intestine were hardened only four days in one sixth per cent. chromic acid, and then four days in the weak spirit, finally being placed in the strong.

Hardening in Chloride of Gold and Chromic Acid.

After washing the tissue in one tenth per cent. chromic acid, it was placed in one half per cent. gold chloride for four hours, and then in one sixth per cent. chromic acid from four to eight days, afterwards in the weak spirit one to two days, and finally removed to the strong.

To obtain the Intestine of an Animal during the Absorption of Fat.

Milk, or milk and cream, were given the animals to drink; or the cream was injected into the intestine (the latter was the plan pursued with hedgehogs), the animal in either case being killed one or two hours afterwards.

Osmic-acid Staining.

The following modification of Basch's (46) method was employed:—The ligature intestine was placed in warm Müller's fluid for twenty-four hours, and at the end of that time small portions were washed in one tenth per cent. osmic acid, and then placed in one to one half per cent. osmic acid for twenty-four hours; they were further hardened in one sixth per cent. chromic acid for six or eight days, left in weak spirit for two days, and afterwards transferred to the strong spirit. The latter was saturated with fat (oil and wax), so that the spirit might not dissolve the fat of the preparations.

Staining of Specimens.

The specimens (with the exception of some which were treated by osmic acid) were stained in a solution of hæmatoxylin. They were left in a strong solution from six to twelve, or even thirty hours. The solution of hæmatoxylin was made in accordance with the receipt given by Dr. KLEIN in the 'Quarterly Journal,' Oct. 1873.

STRUCTURE OF THE MUCOUS MEMBRANE OF THE INTESTINE.

The Epithelium, and the Reticulum and Lymph-Corpuscles among the Epithelial Cells.

On viewing a section of the vermiform process of the rabbit, many small round cells will be noticed among the epithelium covering the apices of the lymphatic follicles. These cells are exactly similar to those in the follicles. They may be situated among the epithelium, as if that tissue were to some extent infiltrated by them; or they may have possession of at least the lower half of the space which ought to be occupied by the epithelium, as in Plate 39. figs. 1 & 2, where they are seen as two or more layers above the basement membrane, the epithelium being apparently eaten away at its lower extremity by the round cells. If the section be a favourable one, and very deeply stained, it will be seen that processes from the dark line on which the epithelium appears to rest run up between the epithelial cells; and where this is the case the epithelium which covers the follicle contains a tissue similar to that found within the follicles. (Identical appearances are met with in the epithelium covering the follicles of the tonsil[*].) Thus we find that the epithelium contains a tissue consisting of a reticulum containing in its meshes lymph-corpuscles.

If, now, sections of the epithelium covering the villi or the villus-like processes of the large intestine be examined in any animal, it will easily be seen that the epithelium contains lymph-corpuscles similar to those in the follicles (see fig. 13). It is specially easy to demonstrate this fact in the intestine of the rabbit and sheep. In preparations treated by chromic acid and stained in hæmatoxylin, these cells are seen to consist of a small zone of unstained protoplasm surrounding a very deeply stained spherical nucleus. *In the following pages I intend to apply the term "lymph-corpuscles" only to these cells.*

Again, if the villi of a recently killed rabbit be examined (either in the fresh state, in saline solution of three quarters per cent., with the addition of weak acetic acid, or after having remained in one per cent. bichromate of potash from two to six days), it is easy to show that the lymph-corpuscles are scattered everywhere among the intestinal epithelium; and it is equally easy to show, if the epithelial cells be separated from one another by teasing, that the lymph-corpuscles are not found within the epithelial cells, but lie between them. Thus ARNSTEIN (40) was mistaken in supposing that these corpuscles were ever contained within the epithelium[†].

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[*] HENLE long ago noticed that the epithelium which covers much developed "agminated glands" of the conjunctiva is thinner from an infiltration of the gland-substance ('Eingeweidelehre,' 1862).

[†] Some observers have described Psorospermiæ as existing within the epithelial cells (KLEBS, VIRCHOW's 'Archiv,' Bd. xvi.). There is considerable difficulty in deciding the exact relations in tissue so abnormal as that where Psorospermiæ are present in any great number; but there is no evidence in my preparations of

If the epithelium which has lain in weak bichromate of potash is teased (and it is best to select the intestine of the rabbit, as in that animal the epithelial cells are more easily separated), the idea that they have processes will soon be refuted. They are seen to be somewhat conical, the lower smaller end being slightly broadened at its termination, as was first shown by BILLROTH (36). Attached to them are shreds of the reticulum*, which always separate with the epithelial cells from the rest of the mucosa. In these preparations rarely, if ever, will an epithelial cell with two nuclei be found: the lymph-corpuscles attached to individual cells may give that impression, but in such a case, by pressing on the cover-glass, and so rolling over the epithelial cells, the attached corpuscles will be seen indenting the wall (see fig. 3). This indentation of the wall has been shown in the drawings of EBERTH (33) (fig. viii. *a* and *b*) and ARNSTEIN (40).

The epithelial cells are closed: perhaps the easiest way to show this is to add weak acetic acid to epithelium of a freshly killed animal, examined in saline solution. If the action be pushed far enough (*i. e.* until the cells are almost transparent and the nuclei very much marked) the well-known seam will be pushed up in the form of a segment of a circle, as has been shown by so many observers, or it may be raised up *en masse.*

Sections of frog's intestine show great differences in the length of the epithelial cells in the same animal; and, as a rule, the epithelium in the rectum is longer than that of the upper parts of the intestine. Any good section will show epithelial cells with processes nearly, if not quite, as long as those figured by HEIDENHAIN (37) and others (see Plate 42. fig. 34, of the epithelium of the stomach of the frog). Considerable differences of length will also be met with in the epithelial cells of the intestine of mammals, partly due to the presence of structures which will be discussed hereafter, under the title of "*Epithelial Buds*" (see Plate 39. fig. 13), and partly due to the fact that the epithelium covering the upper surface of the villi and the upper surfaces of the processes in the large intestine is much shorter, as a rule, than elsewhere.

On examining the projections of the mucous membrane in a section of the vermiform process of the rabbit, fine, almost thread-like processes from the dark line on which the epithelium rests may be seen running among the epithelial cells. This dark line (see figs. 9 and 13, *r*), as we shall see afterwards, is due to the sectional view of the connective-tissue reticulum, which lies surrounding the epithelial cells, and on which they rest.

Again, if sections of villi or folds of the mucosa be examined where the epithelial cells have been cut horizontally near their base (see Plate 40. fig. 4), the polygonal areas of the epithelial cells are seen, and between them very deeply stained bodies (fig. 4, *r*), which

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rabbit's intestine (see Plate 39. fig. 1) for concluding that they are ever contained in the epithelial cells; but, on the contrary, they are probably situated between the cells, the latter being pressed to one side by the invading Psorospermiæ.

[*] This reticulum will shortly be discussed.

rarely show a nucleus. These bodies, by their processes, form a continuous network (or reticulum), the epithelial cells being contained in the meshes.

This reticulum stains very deeply in gold or hæmatoxylin; and in oblique sections it can be demonstrated that the dark line which is present below the epithelium in vertical sections is due to the presence of these bodies, *i. e.* of the reticulum.

The same structures will be observed in a cross section of the epithelial cells of a LIEBERKÜHN'S crypt (see Plate 39. fig. 5, where the reticulum is seen to send processes horizontally round the epithelial cells as well as downwards to join with the reticulum of the mucosa). Thus the bodies forming the dark line are anatomically continuous with the reticulum of the mucosa, and are the uppermost layer of that reticulum. This can also be well seen in an oblique section of a villus, where we can similarly trace the continuity of the reticulum which surrounds the epithelial cells with the reticulum of the substance of the villus.

There is, however, a difference between the reticulum which is found among the epithelial cells and that which elsewhere pervades the mucous membrane, inasmuch as the nodes of the reticulum surrounding the epithelial cells are very broad, and the reticulum itself is very delicate, and this gives the appearance of small cells with branching processes (see Plate 40. fig. 4).

Membrana Propria, of the Villi, and of the processes of the Mucous Membrane of the Large Intestine.

For a long time I conceived that the dark line below the epithelium was the membrana (*r*, figs. 10 & 13, Plate 39); this was found not to be the case. In the colon large cells were seen to be situated below the dark line (see fig. 10); but there was no evidence in these preparations that they formed a membrane. On examining, however, some sections of the villi of a monkey, which were denuded of their epithelium, it was noticed that the villi are bordered by large cells with oval nuclei, that these cells are placed more or less closely together, and have somewhat the character of endothelial plates. In places these cells were found to form a membrane; this was seen if the cells were separated from the mucosa and viewed from above (see Plate 40. fig. 6). We notice in the figure that some of the capillary blood-vessels are attached to the membrane; this is always found to be the case. And we further notice that the membrane has gaps or holes in it. We can show that these gaps or holes are not artificial products, if we compare the section with others prepared and stained in exactly the same manner (see figs. 6, 7, 8). Fig. 7 shows the membrana of a LIEBERKÜHN'S crypt; fig. 8 gives the appearances of two alveoli of the mammary gland: neither in fig. 7 nor in fig. 8 is there any indication of holes in the membrane.

In these preparations of villi, devoid of epithelium and bordered by large cells, the dark line which is generally seen at the base of the epithelial cells can nowhere be found; and this teaches us that the reticulum forming the dark line at the base of the epithelium always breaks off with the epithelial cells, that its connexions with the epithelial cells are much more intimate than with the rest of the villus.

On examining villi which have lain three or four days in weak bichromate of potash, if the epithelium be removed, we see the cells forming the membrana (as in fig. 9). If the tissue is then stained in strong hæmtoxylin for some hours and afterwards teased, the membrane with its attached blood-vessels can be isolated, and we obtain similar appearances to those in fig. 6, which was drawn from a section of a hardened villus.

It has been mentioned that the blood-vessels are always attached to the membrana; the reason for this will be evident by referring to fig. 13 (*e*), where it is seen that the cells forming the membrana are not altogether flat plates, but partially surround the blood-vessels and form a kind of adventitia to them.

In examining sections of the villi of the following animals, a membrana propria, very similar to that of fig. 6, is seen—*i. e.* in the sheep, rabbit, rat, hedgehog, dog, cat, and frog.

The Membrana of LIEBERKÜHN'S *Crypt.*

If in sections this membrane be completely isolated from the surrounding structures and viewed from above, it is seen to be a structureless membrane with nuclei imbedded in it at regular intervals (see Plate 40. fig. 7).

On viewing an *oblique* section of a LIEBERKÜHN'S crypt, however (see Plate 39. fig. 5), the membrane is seen to be composed of large cells, the reticulum (*r*) resting on these cells (*e*), and sending processes between them. The cells have all the characters of an endothelium, and (as is the case with the membrana of the villi) the endothelial plates are really contained in the meshes of the reticulum.

The disposition and terminations of the Muscles in the processes of the Mucous Membrane of the Rabbit's Colon.

On viewing a slightly oblique section of one of the processes of the mucous membrane of a rabbit's colon (see Plate 39. fig. 10), we recognize the epithelium, the dark line below it, and the separate large cells of the membrana, as oval or roundish bodies; we observe also bands of muscle running up between the LIEBERKÜHN'S crypts, and separating into individual fibres. Many of these fibres will be seen apparently to end in the large cells below the epithelium (*m*, fig. 10); others will be found to end in connective-tissue processes, which are also seemingly attached to the cells of the membrana (*m'*, fig. 10). At first sight we are tempted to conclude that the muscles end in these cells; this is, however, not the case. In order to understand the relations of the muscle-fibres to the surrounding tissues, they must be studied in cross sections. This will best be done in sections at right angles to the muscularis mucosa (see fig. 12). Here we find certain points of resemblance to the transverse sections of the epithelial cells. Thus small branched bodies are seen which are attached to one another by their processes, the muscle-fibres being contained in their meshes. Is this appearance, then, due again to a reticulum? and, if so, can this reticulum be shown to be in anatomical continuity with that of the mucosa? Both these questions are answered by observing sections in which the muscularis mucosa is cut obliquely to the direction of its fibres; we there find that the reticulum surrounding the fibres is continuous with that of the rest of the mucous membrane. The same thing may be noticed in cross sections of those fibres which are found in immediate contact with the chyle-vessel. Thus each muscle-fibre is ensheathed in a reticulum; and it is by this reticulum that the muscle-bands running up towards the surface are attached to the cells forming the membrana, or, more correctly, to the reticulum surrounding the cells forming the membrane. The method of their attachment to these large endothelial cells is well shown in fig. 11, where the ensheathing tissue (*r*) is seen to envelop one of the cells of the membrana (*e*). *The reader will notice that the reticulum must be considered not only as a network of threads, but as forming, to some extent, membranous investments.* Thus the muscle-fibres have membranous coverings, which are continuous with and are really part of the reticulum; and the same may be said of the endothelial plates of the membrana.

The Disposition of the Muscle-bundles and the Muscle-endings in the villi.

In those villi of the monkey, hedgehog, or rat where there is only one chyle-vessel, the muscle-bundles run by its side, giving off individual fibres towards the side of the villus; and finally they either run straight on and end by being attached to the membrana at the apex of the villus (see fig. 13), or they may be arched slightly over the vessel, and then they will be attached to the membrana at a point on the opposite side of the villus. In the monkey the involuntary muscles form a membrane at least half-way round the chyle-vessel, and it is doubtful whether they do not entirely surround it; but of this I am not sure, as I have no good horizontal sections. This membrane, which is composed of a single layer of fibres dovetailing into one another, is in contiguity with the endothelium*.

In the hedgehog the muscle-bands contain very few fibres, generally only two or three, so that only a small portion of the wall of the chyle-vessel is in contact with muscle-fibre.

In the rat the bands are reduced to the smallest dimensions, sometimes even to rows of single muscle-fibres slightly overlapping at their ends.

In the broad villi, as those at the commencement of the duodenum, in the dog and cat, and in the villi of the sheep, there are many bands running up the villi, which branch, anastomose, and finally end by being attached to the membrana†. I have one preparation of the sheep's intestine where one of the uppermost anastomosing bands, running nearly parallel to the surface epithelium, gives the appearance of a transverse band of muscles.

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* It is difficult at first sight to understand how fat can pass through this membrane to the chyle-vessel; we have, however, seen that each muscle-fibre is surrounded by the reticulum, and it will be further shown that the fat travels by that reticulum.

† Kölliker (61) noticed that in the broad villi of the commencement of the duodenum and jejunum the muscle-bands are spread out like a membrane, and run from the base of the villus to the top.

From what has been explained before of the relation of the connective-tissue reticulum to the individual muscle-fibres, it will be easy to understand that the reticulum surrounding the bundle of fibres is attached to the reticulum of the mucosa, each fibre having here, as in the colon, its own ending: if the fibres end near the membrana, they may be apparently attached to the large cells composing it.

Structure and Relations of the Blood-vessels of the Mucosa.

These vessels have an adventitia—that is to say, in sections showing the longitudinal course of the vessel, threads are seen attaching the vessel to the reticulum of the mucosa (see Plate 40. figs. 15, 17, and 18). There is, however, considerable difference in the arrangement of this adventitia as regards the arteries and veins.

First, as regards the arteries. In those places where the minute arteries have a distinct and continuous layer of involuntary muscle-fibres*, as in the commencement of the duodenum in some animals (*i. e.* in the dog, rat, and hedgehog), the reticulum passes between and surrounds the involuntary muscle-fibres (see fig. 15). Whether the reticulum penetrates between the endothelial plates of the artery, I have been unable to discover.

In other parts of the mucosa we find arteries without a continuous layer of muscle-fibres—that is to say, the muscles are situated at some distance from one another; where that is the case, the reticulum surrounds the vessel much as it does in the former case (compare figs. 16 & 15).

A somewhat similar appearance to that in fig. 16 would no doubt be given by a longitudinal section of an artery in which the muscle-fibres were situated principally above or below the vessel, as in such a section most of the fibres would be cut near their ends; the fibres would then look like clear rings, and would show no trace of nucleus. That this explanation is, however, not suitable is proved by sections which are thick enough to show the whole vessel: by focusing up and down in these sections, we can assure ourselves that there is no continuous layer of involuntary muscle-fibres surrounding the artery, and that there are only a few fibres at rare intervals; and in such a preparation, on accurately focusing the lumen of the vessel, we obtain an appearance similar to fig. 16.

In the minute arteries of many villi there are no involuntary muscle-fibres at all; we shall, however, often be able to recognize the arterial character of these vessels by the marked adventitia.

Secondly, as regards the relations of the adventitia to the veins.

In the veins the adventitia is not so distinctly seen as a separate membrane; it can, however, be shown to exist, and an adventitia is present here in the same sense that an adventitia may be said to surround the involuntary muscle-fibres. See fig. 18, where in places the reticulum surrounding the vessel is seen, and compare figs. 17 & 18.

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* DONDERS (12) noticed ring-shaped nuclei around the arteries in the villi.

Not only does the reticulum surround the endothelium, *but we can also show that it penetrates between the individual endothelial cells.* This is seen if we examine a longitudinal section of a broad vein, and view the inner surface of the vessel from above: see Plate 40. fig. 19, where we find a delicate reticulum between the individual cells. Nor must we be surprised that the reticulum is very delicate, as it has been shown that membranes, when viewed from the surface and separated from the rest of the tissue, show no trace of the reticulum (see figs. 6 & 7), although in oblique sections of these membranes *in situ* (as in Plate 39. fig. 5), as we have seen, it is quite easy to demonstrate a reticulum among the separate endothelial cells.

It has already been mentioned that the cells of the membrana propria partially surround the superficial capillaries.

The Character and Relations of the Chyle-vessels of the Villi.

In the cylindrical villi the central canal is somewhat club-shaped, the lower end being much narrowed. The villi of the hedgehog are best adapted to demonstrate the chyle-vessels in sections, as in that animal they are very large, and are not surrounded by many involuntary muscle-fibres.

The walls of the chyle-vessels are composed of endothelial plates. The relation of the reticulum to the chyle-vessels is almost exactly similar to its relation to the veins; *i. e.*, in longitudinal sections of the vessel, threads are seen attached to the wall, which are continuous with the reticulum of the mucosa (see Plate 41. fig. 22), whereas, on viewing the vessel from above, there is seen to be a delicate reticulum penetrating between the endothelial plates (see fig. 20).

If the chyle-vessel be cut rather obliquely, as in fig. 21, we notice that the reticulum surrounding the cells of the mucosa is continuous with that which envelops the endothelial plates. This specimen was drawn from a villus situated above BRUNNER's glands in the dog: it will be seen that in the upper part of the chyle-vessel the cells of the villus and the endothelial plates of the chyle-vessel are continuous.

In sections of the cylindrical villi, if the cells of the tissue have been accidentally removed, threads of the connective-tissue reticulum are seen attaching the upper widened end of the chyle-vessel to the membrana (see Plate 39. fig. 14).

The Tissue composing the Mucosa.

The mucous membrane contains no fibrous tissue. Probably the involuntary muscle fibres, with their intervening threads of reticulum, have been mistaken for it.

The mucosa is everywhere composed of a reticulum and of cells held in its meshes. Wherever the intestine contains lymphatic follicles, it can be shown that the reticulum of the follicles is continuous with that of the rest of the mucosa; and there are many places in the mucosa where the cells contained in the meshes of the reticulum are only lymph-corpuscles.

What, then, is the tissue of a villus? Is it the same as that of the rest of the mucosa, as is often assumed? And is the tissue of the mucosa the same as that found in a follicle of a PEYER's patch? It is very important to be clear on this point, as it is certain that fat-absorption cannot be properly understood unless we perfectly understand the structure of the villi, a fact which has been much lost sight of. The difference between the tissue of the villus on the one hand and of a follicle of a PEYER's patch on the other, is not to be found in the reticulum (which is identical or very similar), but in the cells contained in that reticulum.

In the lymphatic follicles, and in parts of the mucosa, the cells are entirely lymph-corpuscles*. In the villi, though lymph-corpuscles are always present and may be almost the chief constituent (as in the sheep), or an important constituent (as in the rabbit), yet in some animals they are few in number (as in the dog and cat), or even rare (as in the monkey), in this situation.

What, then, is the character of the cells of the villi? They are polygonal cells composed of a very pale protoplasm with an oval nucleus. These cells differ from lymph-corpuscles:—first, in size, they are more than twice as large; secondly, they differ in having a large zone of protoplasm around the nucleus; and thirdly, they differ in regard to their nuclei, which are oval and stain very lightly, as contrasted with the spherical deeply staining nuclei of the lymph-corpuscles. Let the reader compare the two kinds of cells in fig. 13 (Plate 39). Nevertheless, as can be seen in fig. 21 (Plate 41), the cells of the upper part of the villus are larger than those near the base; and it is no doubt true that there is every transitional form between the lymph-corpuscles of a lymphatic follicle and the cells of the upper part of the villus.

These cells of the villi are seen in sections to be arranged almost like an endothelium (see figs. 21 & 22); and in the upper part of the villus they are very similar to the endothelial cells of the membrana propria, of the veins, and of the chyle-vessel. See fig. 13, where the cells of the villus are not to be distinguished from those of the membrana propria; and see fig. 19, where there is great similarity between the endothelial cells of the vein and the cells of the villus. We have already noticed in fig. 21 that in the upper part of the villus the endothelial cells of the chyle-vessel and the cells of the villus are continuous and similar.

We have seen above that the mucosa is composed of a reticulum containing cells in its meshes; these cells are (*a*) lymph-corpuscles and (*b*) large flat cells similar to endothelial cells: the latter may therefore be considered to be connective-tissue corpuscles. We have further seen that there is a gradual transition from the one kind of cell to the other.

It has now been demonstrated that there is everywhere a reticulum holding all the elements of the mucous membrane in its meshes; and if this account of the minute anatomy of the mucosa be correct, fat-absorption can only take place by means of the reticulum, or by the cells, or through both. Though my researches on fat-absorption have not been numerous, yet, as they show the fat to be in a reticulum, and as that reticulum is attached to the muscles and to the chyle-vessels in exactly the same way as I have shown that the reticulum is attached in preparations hardened in chromic acid, I conceive them to be sufficiently convincing.

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* I have already defined the cells which are spoken of in this paper as lymph-corpuscles. See page 459.

Fat-absorption by the Reticulum among the Epithelial Cells.

To obtain preparations showing the fat between the epithelial cells, an animal was killed during the absorption of fat, and the intestine hardened in osmic acid, according to the methods given above; small portions of the mucous membrane were teased. The teased preparations were then treated with a dilute solution of caustic potash, until the tissue became much more transparent; they were then placed in glycerine. If, in such a preparation, a horizontal view of separated epithelial cells be examined, it is seen that fat-granules are arranged in lines between the cells, the epithelium being free from fat-particles (see Plate 41. fig. 23).

In examining sections of an intestine hardened as above, if we view the epithelium where it has been cut transversely, we have appearances very similar to those we have just described, *i. e.* the fat-granules are arranged in lines between the epithelial cells. If in the section the epithelium be cut vertically, although there are distinct lines of fat-granules between the cells, yet, as a rule, the appearances are not so satisfactory, as the cells appear to contain particles of fat.

Examination of teased preparations will show isolated epithelial cells apparently filled with fat, as has been figured and described by so many observers. It must, however, be remembered that the reticulum always breaks off with the epithelium, and that it is difficult to decide whether the fat which we see apparently in the epithelial cells is lying in them or in the shreds of reticulum attached to them; by pressing on the cover-glass and rolling over these isolated epithelial cells, the fat is generally seen to be arranged in lines along their borders.

From the foregoing observations I have concluded that there is proof that the fat travels by the reticulum between the epithelial cells, but that there is no decisive evidence that fat-granules are absorbed by the epithelial cells.

This reticulum has been seen and described by a great number of observers under various names. It has been seen in the most different epithelia; it has been shown to be capable of absorbing various substances; and there are some observations which prove that injections have penetrated into it.

Thus, REICH (109), PFLÜGER (62), HEIDENHAIN (110), LANGERHANS (63), GIANUZZI (64), BOLL (65), SAVIOTTI (66), EWALD (67), EBNER (68), LEYDIG (69), and LATSCHENBERGER (70), have seen it in the salivary glands or pancreas; while it was described as nervous tissue by REICH (109) and PFLÜGER (62), or as connective-tissue by BOLL (65), it was injected and considered to be intercellular salivary capillaries by GIANUZZI (64), LANGERHANS (63), SAVIOTTI (66), BOLL (71), and EWALD (67); LEYDIG (69) and LATSCHENBERGER (70) thought that there were only intercellular spaces between the cells; HEIDENHAIN (110) concluded that this tissue was a continuation of the cell-membrane; EBNER (68) deemed it to be a cuticular formation which was probably connected to the membrana propria.

SCHWALBE (72) noticed the tissue in BRUNNER'S glands; he spoke of it as secretion-capillaries with a coagulation of their contents.

Similarly GIANUZZI and FALASCHI (73) described interepithelial secretion-capillaries in the mammary gland.

This tissue was seen in the "rete Malpighii" of the skin as small branched bodies, staining deeply with gold: these bodies are probably connected with nerves: CHRSCHTSCHONOWITSCH (74), PODCOPAËW (75), and ELIN (76). This connexion was not made out by LANGERHANS (77), EBERTH (78), and EIMER (79).

This tissue was described in the intestine by FLES (53), ERDMANN (34), and ZAWARYKIN (56). FLES and ERDMANN considered it to be cement substance, and probably connected with the connective-tissue reticulum of the villus; while ZAWARYKIN spoke of it as the borders of the epithelial cells; ERDMANN and ZAWARYKIN noticed that absorption took place by this tissue.

Possibly this tissue was seen in the serous membranes by ŒDMANSSON (80) and DYBKOVSKI (81), who described openings between the endothelium of the serous membranes.

This tissue was described and figured by KLEIN (82) in the serous membranes, as pseudostomatous tissue. KLEIN considered this tissue to be of the greatest importance in absorption.

Probably it is this tissue which was seen in the lymphatic vessels, and described as stomata by HIS (51) and RECKLINGHAUSEN (83), and as stigmata by ARNOLD (84).

The same tissue was seen in the epithelium of the alveoli of the lung, and in the epithelium of the bronchi, by SIKORSKY (85), KLEIN (86), WITTICH (87), and KÜTTNER (88). KLEIN has figured it as intraepithelial nucleated branched cells in connexion with the connective-tissue corpuscles of the mucosa, the latter being in anatomical continuity with the lymphatic vessels.

Finally, it has been seen and described as cement-substance by ARNOLD (89) in epithelium of the tongue and palate of the frog.

Injections have been forced into it from the blood-vessels by CARTER (90) in many places, as in the palate of the frog and in the reticulum of the lymph-follicles of the intestine, in the epithelia of the skin and mucous membranes, and between the involuntary muscle-fibres of the arteries. By ARNOLD (89) also injections have been forced into it in many places; and by THOMA (91) a precipitation was obtained in it (in the living animal) by a natural injection.

Injections have also been forced into it from the lymphatics, by KOWALEWSKY (92) in the lymphatic glands, by DYBKOVSKI (81) in the pleura, and by BASCH (54) in the tissue of the villus.

This tissue has been found to absorb coloured fluid in recently killed animals, WITTICH (87), and in living animals, ZAWARYKIN (56), SIKORSKY (85), and KÜTTNER (88). ZAWARYKIN and KÜTTNER, in making experiments on the absorption of coloured fluids, found that lines between the endothelial cells of the lymphatic vessel are marked out by the colouring-matter.

Fat-absorption by the Reticulum of the Villi.

A glance at figs. 24 & 25 (Plate 41) will give the appearances I have now to describe: these preparations are from the intestine of the hedgehog. The similarity of the reticulum (filled with small fat-granules) to that which is seen in preparations treated by chromic acid is obvious (compare figs. 21 & 22 with figs. 24 & 25). There is only one difference, and that is due to the different reagents. The reticulum is always broader in preparations which have been hardened in MÜLLER's fluid and osmic acid, than it is in those preparations hardened in chromic acid or alcohol (see figs. 41 & 39, Plate 43).

In conclusion, we find that the fat travels by the reticulum which is found everywhere among the other elements of the mucosa.

I can confirm those observers who have asserted that LIEBERKÜHN's glands absorb. There is, however, much less absorption from these glands than from the surfaces of the villi.

What are the forces causing absorption? No doubt the emptying of the chyle-vessel by the muscles surrounding it, and the subsequent erection of the villi, tend to promote absorption. Probably, however, absorption is not the purely mechanical process of particles of fat being pressed through a soft semifluid mass (the reticulum); on the contrary, it is more probable that the reticulum takes an active part in the process*.

CHAPTER II.

THE MINUTE ANATOMY OF THE MUCOUS MEMBRANE OF THE PYLORIC END OF THE STOMACH.

HISTORY.

TODD and BOWMAN (32) first showed the great difference between the glands near the pylorus and those of the rest of the stomach. They found that the epithelial cells of the surface are continued into wide cylindrical tubes, which end in very short and diminutive tubes lined with a "subcolumnar" epithelium.

This difference between the glands of the pylorus and those of the rest of the stomach was confirmed by DONDERS (12) and KÖLLIKER (93).

KÖLLIKER (61) found bands of muscles from the muscularis mucosa running between the glands even into the plicæ villosæ.

KLEIN (94) explained the manner in which the bands of muscle in the lower part of the mucosa decussate, "forming a kind of pocket" . . . "embracing the several tubes." He found that some of the fibres "extend as far as the epithelium."

EBSTEIN (95) first accurately described the character of the cells of the proper gland-tubes, and he also described the changes occurring in digestion. This paper will be referred to again.

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* BUSK and HUXLEY, in a note to the translation of the Manual of Human Anatomy by A. KÖLLIKER, 1854, said, "We should rather compare the manner in which fat enters a villus to that in which the ingesta enter an *Actinophrys*."

LOVÉN (96) discovered lymph-vessels in the mucosa of the stomach extending into the plicæ villosæ.

RABE (97) noticed that, in the horse, the glands are of uneven length, and that this gives the mucosa a somewhat wavy surface. .

The general structure of the Mucous Membrane.

If we harden the pyloric end of the stomach of a dog in chromic acid and examine the surface with the naked eye, the mucosa, with the exception of a few large folds, presents a somewhat smooth surface. On examining this apparently smooth surface more carefully with the aid of a simple lens, we shall find that it is formed of a number of minute elevations and depressions. The principal elevations are parallel to the transverse axis of the stomach; but they communicate by short branches running in the longitudinal direction, and thus they form a network of irregularly shaped meshes*. On making a longitudinal vertical section of the pylorus, these elevations are seen to be rounded, and give the mucous surface a wavy aspect.

We notice, in the section, that the upper part of the stomach-tubes which open on the summit of these elevations is straight, and that the plicæ villosæ between the tubes are straight and long; whereas the tubes which open into the depressions are shorter and wider, and their sides are folded (see fig. 26, Plate 42, where we find alternations of long straight tubes and of short tubes); and these appearances are very like those which EBSTEIN (95) has given in his fig. iv. and fig. iii. as representations of the stomach of a dog in stages of sponge feeding and of vegetable feeding respectively.

These wave-like elevations of the mucous membrane of the stomach with the accompanying differences in the length of the tubes are seen in dogs killed in all stages of digestion and hunger, and they are therefore to be considered a constant feature of the dog's stomach.

This feature is, however, not always well marked, if the stomach has been hardened in alcohol; and it was completely absent in the stomach (hardened in alcohol) of a dog which had been fed on sponge after the manner of SPALLANZANI and EBSTEIN (95).

It has been found that, as a rule, the mucosa is more contracted in digestion than in hunger; this is also true of the plicæ villosæ, which are more expanded in sections made from the hardened stomach of an animal killed while fasting, than in sections made from an animal killed during digestion.

The wave-like elevations of the surface of the pyloric end of the stomach are well marked in those animals which have very compound glands and much convoluted gland-tubes, as in the dog and horse. In the monkey, rabbit, and hedgehog these foldings of the surface are much less marked. In the rat the tubes are of even length, and the surface of the stomach is quite smooth.

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* KÖLLIKER (44) has described a network of folds on the surface of the pylorus.

If we examine a vertical section of the pylorus, we notice that the epithelium of the surface is continued downwards into wide cylindrical tubes (*d*, fig. 26, Plate 42). These tubes divide, at their lower extremity, into two short branches, and into each of these short divisions two or three small branching twisted tubes (*ct*, fig. 26) open from below. That part (*d*) of the stomach gland-tubes which is lined by cylindrical epithelium will be called the duct. The smaller tubes (*ct*) will be called the proper glands or coiled tubes.

The Epithelium covering the Pyloric end of the Stomach.

TODD and BOWMAN (32) thought that when the cells have arrived at maturity the granular contents escape "by a dehiscence or opening of the wall at that part," "leaving the transparent husk with its nucleus subsisting for some time longer." The clear structureless mucus which occupies the cells and covers the surface "seems to be altered contents" of the cells.

F. E. SCHULZE (98) spoke of the cells as being open above; he showed that by the action of some fluids the contents of the upper part of the cells swell to a very voluminous mass.

EBSTEIN (95) thought that the cylindrical epithelium has closed ends; that in digestion these cells, owing to extreme mucous metamorphosis, burst, and are then open above.

I have found that in certain stages of secretion these cells are open; but if the animal has been kept some time without food, the substance of the cell is definitely bordered. This can be demonstrated by examination of the stomach of a recently killed rabbit which has been kept twenty-four hours without food. The stomach is to be placed in five per cent. salt solution for one hour, and then examined in saline solution of three quarters per cent. We shall then see that the epithelium is closed. On adding weak acetic acid, all the cells pour out a large quantity of semifluid substance and become goblet-cells. I must therefore agree with TODD and BOWMAN (32) and EBSTEIN (95) in considering the cells to be closed; but differ from F. E. SCHULZE (98) and BLEYER (99), who hold that they are always open.

Germination of the Epithelium.

Almost all the phenomena which will be described under this heading are equally true for the epithelium of the intestine. They will be described in connexion with the stomach, because I first noticed the method of increase in the epithelium of the plicæ villosæ, and because the accompanying drawings have been made chiefly from that region.

(A) If the stomach has been stained in gold and hardened in chromic acid, *many of the epithelial cells covering the surface will be found to contain nuclei in a state of division* (see fig. 27, Plate 42)*. It is noticed that the division does not seem to take place according to any strict law, as some of the nuclei are divided transversely, some longitudinally, and some obliquely.

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* This preparation is from the colon of the rabbit; the appearances are very similar to those in the stomach.

(B) In preparations hardened in chromic acid, *small cells are found at the base of the epithelium.* This fact was described by TODD and BOWMAN (32), who seem to have thought that a second layer was always present. F. E. SCHULZE (98) (Taf. x. fig. vi.), EBSTEIN (95) (fig. i.), and BLEYER (99) have also described small cells at the base of the epithelium.

These cells are of two kinds:—first, lymph-corpuscles similar to those which have been described among the epithelial cells of the intestine (see fig. 28, Plate 42); and secondly, rounded or conical cells which are only found at the base of the epithelium (see figs. 29 and 32)*. These latter cells have a faintly granular protoplasm, and contain spherical nuclei which are not readily stained by hæmatoxylin. These cells may therefore be distinguished from the lymph-corpuscles, which have been already described as consisting of a small clear zone of protoplasm surrounding a very deeply stained spherical nucleus (compare fig. 28 and fig. 29).

(C) In similar preparations *we find short broad epithelial cells,* showing a faintly staining cell-substance containing a large pale nucleus, which may be divided (see fig. 30).

(D) And, finally, we see *groups of epithelial cells composed of two or three, or even more, cells arranged very much like a bud* (see figs. 13, 31, 33, where it will be seen that the base of the group of cells projects slightly into the mucosa). These groups of cells are the structures which I propose to call "epithelial buds."

The same features are seen in the small round or conical cells of figs. 29 & 32, and in the short broad cells of fig. 30, and in the epithelial buds of fig. 33. These features are a spherical nucleus, as opposed to the oval nucleus of ordinary epithelium, and a faintly granular protoplasm of the cells, which is not easily stained by hæmatoxylin.

Now it seems to me reasonable to form the following conclusions from the appearances described at (A), (B), (C), (D):—that the epithelial cells divide; that the small rounded cells of figs. 29 and 32 are the products of their division; that these small cells, increasing in size and rising up among the older cells, push them to one side, and form the short broad cells as represented by fig. 30; and that these short broad cells, by division, form the bud-like structures of figs. 31 & 33. The view that the buds are caused by division is favoured by the appearance of the epithelial cells next to the bud-like groups. They are always compressed together, are deeply stained in hæmatoxylin, and contain a considerable amount of mucus.

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* Fig. 29 is drawn from a preparation which had been stained in hæmatoxylin; the upper part of the cells is seen to be intensely stained, and in the original preparation was of a deep blue colour. The cells are open and contain mucus. It is the mucus which has been stained so readily. That mucus is very readily stained a blue colour by hæmatoxylin, has been shown by me in a short note to the Royal Society (Proceedings, vol. xxii. p. 293). I have there described the different manner in which the cells of the mucous glands of the tongue are acted on by staining fluids, in states of inanition and secretion. Specimens stained first in hæmatoxylin and then in carmine showed that during inanition the cells contain mucus, and their contents are more easily stained by hæmatoxylin than by carmine; whereas during secretion the carmine will stain the cell substance more readily than hæmatoxylin; any mucus in the ducts of the glands is, however, stained an intensely blue colour.

The bud-like groups are sometimes found of considerable size, and, when this is the case, they call to mind the foldings of the epithelium, which have been described in the intestine by DONDERS (12) and KÖLLIKER, and figured by TODD and BOWMAN*; they have also been figured by EBSTEIN† in the stomach. These buds are found, however, not only on the sides of the villus-like processes of the stomach, but also on the flattened surfaces of those processes; and they are seen among the epithelium covering the sides of the villi of the intestine, or on the sides of the plicæ villosæ, where there is no apparent folding of the epithelium. If, however, the short plicæ villosæ (in the depressions between the wave-like elevations of the stomach) be examined (see fig. 26, Plate 42), the epithelium is seen to be in folds, giving the appearance of large buds. Whether we have here one of the plicæ villosæ, temporarily shortened by the contraction of its muscles, with a consequent folding of the epithelium, or whether we have some more permanent process associated with repair, I have no evidence on which to decide.

These bud-like structures are found in great numbers in young animals, and at first it seemed possible that these buds were the means whereby the epithelium increases in growing animals; and possibly it may be so, as REMAK (100) has observed in the intestine the increase of epithelium by longitudinal division. These buds may, however, be seen in the epithelium of animals which have attained their full maturity, as was proved by sections made from the stomachs of five dogs, of the ages of two years and upwards. I consider, therefore, that these bud-like structures are concerned in the repair of the epithelium, and that this repair is constantly needed during the life of the animal.

The foregoing results were obtained from a great number of observations, and were chiefly made from sections of the stomach of the dog. I have, however, one preparation from the pyloric end of the frog's stomach (Plate 42. fig. 34), which may possibly be explained by the view that DONDERS (12) and KÖLLIKER (93) took of the regeneration of the epithelial cells—*i. e.* "that the cylindrical cells of the intestine not unfrequently burst at their apices, and allow a part of their contents (mucus) and their nucleus to pass out; a second, previously formed cell-nucleus then serves for the regeneration of these cells; . . . . these are the cells designated by GRUBY and DELAFOND 'epithelium capitatum,' *i. e.* goblet-cells."

The Connective-tissue Reticulum among the Columnar Epithelium.

This reticulum is, in its character, exactly like that which has been already described among the epithelium of the intestine, and can be best seen among the epithelium of the ducts (see fig. 35, Plate 43). It is much harder to demonstrate its occurrence among the epithelium of the surface of the plicæ villosæ; and though it does exist even among that epithelium, it is very fine and delicate, and does not appear to reach the surface. There is, however, an intercellular substance uniting the upper surfaces of the epithelial cells, which differs very materially from the connective-tissue reticulum, in the fact that it does not stain at all in hæmatoxylin.

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* *Loc. cit.* fig. 159.

† *Loc. cit.* fig. iii.

The Character of the Membrana Propria.

The membrana propria of the surface of the villus-like processes is formed of endothelial cells. In section they are seen as oval or rounded cells; on surface view they appear as polygonal plates. I have never been able to separate the membrana from the rest of the mucosa. The membrana of the ducts, when seen from the surface and completely isolated from the surrounding structures, is exactly like that of LIEBERKÜHN's crypts, namely, a structureless membrane, with oval nuclei imbedded in it at intervals.

The Muscle-endings in the Plicæ Villosæ and the Perivascular Spaces.

In specimens hardened in chromic acid, the muscles arising from the muscularis mucosæ are seen passing up between the glands and entering the plicæ villosæ. If these villus-like processes of the mucous membrane are very narrow, two bundles of muscular fibres will be seen, one on each side of a central clear space, and in contiguity with it. The muscle bands running up to the tops of the plicæ villosæ and spreading out, end by being attached to the membrana; some of the fibres may cross above the clear space, or pass to the side of it to be attached to the membrana of the other side of the villus-like process; the mode of their attachment is exactly like that which has been already described in the colon of the rabbit (compare fig. 36, Plate 43, with fig. 10, Plate 39).

The clear space enclosed by the muscle bands is seen to contain a blood-vessel, and is formed of endothelial plates.

The blood-vessels in the narrower plicæ villosæ run vertically, but, at times, they bend horizontally. If in the section they bend towards the observer, the blood-vessel is seen to be surrounded by a clear ring (perivascular space). In the broad villus-like processes where the blood-vessels run in a direction parallel with the surface, the upper wall of the perivascular space is formed by the membrana propria: thus we have here an arrangement somewhat similar to that described by BOLL (71) and LEYDIG (69) in the salivary glands, and by LUDWIG and TOMSA (101) in the testicle, namely, a blood-vessel enclosed in a perivascular space, one wall of which is formed by the membrana propria, the membrane supporting a secreting epithelium.

These perivascular spaces are probably the same as those lymph-vessels of the stomach which have been injected by Professor LOVÉN (96) by the method of puncture (*loc. cit.* figs. iv. & x.).

In the broad villi great numbers of muscle-fibres are always present; and fig. 36 shows how they form membranous layers, which lie in contiguity with the endothelial plates of the perivascular membrane. This arrangement reminds us at once of the relation of the muscle-fibres to the walls of the chyle-vessels of the villi in the monkey. The action of the muscles on the plicæ villosæ will be twofold: when they contract they will shorten the villi, and further they will cause them to become smaller in their transverse diameter. This follows from the disposition of the bands of muscle: they expand in a fan-like manner in the upper part of the villi, some of the fibres crossing over to be attached to the other side.

The proper Gland-tubes of the Pyloric end of the Stomach.

These tubes contain a different epithelium to that in the ducts, as EBSTEIN (95) first pointed out. He described the character of the epithelium of these glands in animals killed while fasting and also during digestion; he found that in the former case the cells are composed of a transparent, faintly granular cell-substance, the nuclei being situated at the base of the cells (*loc. cit.* fig. ii.); in the latter case the cells become cloudy with granules, are shrunken, and are deeply stained by carmine or anilin; and EBSTEIN has figured (figs. iii. & iv.) the nuclei as spherical in form.

If, in a vertical section of the stomach, we examine a part of one of the coiled tubes running vertically, and view the tube from the outside, we notice between the epithelial cells a fine reticulum, similar to, but much finer than any we have seen before (see fig. 37, Plate 43). The nuclei of the epithelial cells are seen from this point of view as circular bodies, and are stained very slightly by hæmatoxylin, the cell-substance hardly being stained at all; the reticulum is deeply stained. If in the section we find a tube which has been cut transversely (so that the epithelium is cut vertically), we notice the separate epithelial cells resting apparently on the basement membrane, and we find a dark line at the base of each cell (see fig. 38, *a*). To what is the dark line due? No doubt, in some measure, to the nuclei; and we should expect the flat circular nuclei when seen from the side (that is to say, when the light has to pass through their long diameter) to intercept the light more than when viewed from above or below. But that the dark line is due to something else than the nuclei, is easily seen where the cells are placed rather obliquely to the line of the section (see fig. 38, *b*). Here we can partly see the nuclei, and yet the dark lines are present. In sections which have cut the epithelial cells more obliquely, we find that the dark line is partly formed by the connective-tissue reticulum (see fig. 39). It has been already mentioned incidentally in Chapter I. that the reticulum is more marked in specimens which have been hardened in MÜLLER'S fluid and osmic acid than in those which have been hardened in chromic acid (let the reader compare figs. 39 & 41).

This reticulum has been seen by SCHWALBE (72), who spoke of it as a network of canals, a layer of granular cell-substance being found between the membrana and the polygonal network; he also found the nuclei not within the meshes of the network of canals, but lying over one of the meshes (*loc. cit.* fig. xiii.).

It has been mentioned above that EBSTEIN (95) has figured the nuclei of these cells as spherical in form in animals killed during digestion. I have examined a great many dogs in various stages of digestion, hardening their stomachs in chromic acid, and, with very few exceptions, the nuclei have been found as flattened disks, lying at the bottom of the cells, as in fig. 38. Sometimes, it is true, the nuclei are seen to be spherical, as in figs. 39 & 40; but this never occurs over any considerable tract of the stomach. I can, however, confirm EBSTEIN'S statement that the cells are more granular and stain more readily during digestion than during inanition. In tissue which has been washed in one tenth per cent. chromic acid and immediately placed in alcohol, I have equally failed to find the nuclei as spheres in the cells of animals killed during digestion.

Besides these two forms of nuclei, a third is sometimes met with (see Plate 43. fig. 40, *b*). There appears to be here some process of vacuolation of the nucleus; and this form is possibly an intermediate state between the disk-like and the spherical form of nucleus. Cells with nuclei in a state of vacuolation are not very frequently met with. They have been only found in animals killed during digestion.

The membrana of the coiled tubes is exactly similar to that of the ducts of the tubes or that of LIEBERKÜHN'S glands.

I must leave to another paper any complete description of fat-absorption in the stomach, only observing that in sucking animals the epithelium covering the surface is seen apparently completely filled with fat. This fact was noticed by BRUCH (102) and KÖLLIKER (103). In fully developed animals no fat can be observed in the epithelium covering the surfaces of the plicæ villosæ; but the epithelium of the ducts and of the coiled tubes appears cloudy with fat, and this is much marked in animals whose stomachs contain bile. It is not intended by the foregoing remarks to give any opinion as to the method of fat-absorption in the stomach.

The occurrence of lymphoid follicles in the mucosa will be discussed in the next chapter.

CHAPTER III.

THE MINUTE ANATOMY OF THE MUCOUS MEMBRANE AT THE POINT OF TRANSITION BETWEEN THE STOMACH AND INTESTINE.

In the following Chapter the anatomical continuity of BRUNNER'S glands with the coiled tubes of the stomach will be described. But before proceeding to the relation of the facts a short account of the history of the subject will be given.

BRUCH (104), 1849, spoke of racemose or acinous glands of the pylorus, which pass into the acinous glands of the duodenum (BRUNNER'S glands).

ECKER (105), 1852, said that the racemose glands of the portio pylorica form an obvious transition to BRUNNER'S glands.

This fact was either overlooked or denied until

COBELLI (106), 1864, found, in the pyloric end of the stomach of man, branched mucous glands and acinous glands. The acinous glands are arranged in rows or little heaps radiating from the pylorus. At the commencement of the intestine the glands of BRUNNER were found in the submucosa and in the mucosa; the muscularis mucosæ at this point is very incomplete; further down the intestine there is a definite muscularis mucosæ, and the glands of BRUNNER are only found in the submucosa. From these observations the acinous glands of the portio pylorica may be "considered as a continuation" of BRUNNER'S glands. In the rabbit and dog only mucous glands were found in the pyloric end of the stomach. In the cat and in the *Mustela putorius* acinous glands occur in the pyloric end of the stomach. In all animals there exists a short tract where the glands of LIEBERKÜHN are wanting, and where BRUNNER'S glands are placed both in the submucosa and in the mucosa. Follicles were found at the commencement of the duodenum in the dog and cat.

SCHLEMMER (107), 1869, showed that BRUNNER's glands are tubular.

SCHWALBE (72), 1871, confirmed SCHLEMMER, and proved the great similarity between the epithelial cells of the tubes of the pylorus and those of BRUNNER's glands. He said that the cells of BRUNNER's glands are like those of the stomach-glands in active secretion.

HEIDENHAIN (108), 1871, agreed with SCHWALBE as to the tubular character of BRUNNER's glands, and their great analogy to the stomach-glands of the pylorus.

If the point of union of the stomach and intestine in the dog be examined with the naked eye, lymphoid follicles are seen to be present in varying number. In some dogs they are so numerous that they form a ring of about half an inch in breadth at the commencement of the intestine, the surface being almost completely covered by them.

In sections made at right angles to the plane of union of the stomach and intestine, it will be seen that the character of the epithelium of the surface changes quite suddenly. This change in the character of the epithelium indicates the point of transition between the stomach and intestine. In specimens hardened in chromic acid and stained in hæmatoxylin, we see on one side the regularly arranged cylindrical epithelium of the stomach, which in its upper part is clear and almost unstained; on the other we find the granular epithelium of the intestine, with goblet-cells at intervals. This change of epithelium is found not only on the surface but in the tubes, so that at this point the glands of LIEBERKÜHN may be said to commence. There is, therefore, no gradual change, but suddenly the ducts of the stomach-tubes leave off, and the LIEBERKÜHN's glands begin. This opinion is confirmed by preparations hardened in osmic acid, where it can plainly be seen that the ducts of BRUNNER's glands do not open into the crypts of LIEBERKÜHN, but run up between them, as has been represented in the figure.

In viewing the section made at right angles to the plane of union, we notice that the stomach-glands near the point of union are slightly different to those of the rest of the portio pylorica, the proper glands (coiled tubes) are more branched and convoluted, and the ducts are somewhat shorter. It will be further noticed that the coiled tubes are found penetrating (or even to some degree extending below) the muscularis mucosa. At about the point of union between the stomach and intestine, the coiled tubes will be found to break through the muscularis mucosa to a greater degree; and at the commencement of the intestine we shall find that there are as many of these tubes in the submucosa as in the mucous membrane. At this point the muscularis mucosa is generally rather indefinite, as it splits up, and portions of it run among the lobes of the coiled tubes. These tubes, from their situation, must now be called BRUNNER's glands. On examining the section still further down the intestine, but few coiled tubes will be found above the still somewhat irregular muscularis mucosa; while below it, BRUNNER's glands are more regularly arranged in the form of separate lobes. Still further in the section we find a continuous muscularis mucosa with numerous LIEBERKÜHN's crypts reaching down to it, while BRUNNER's glands consist of smaller lobes entirely below the muscularis mucosa. Finally, the lobes are smaller and more isolated, and then cease.

In the mucosa, as has been already stated, lymph-follicles are found in varying number. They may form almost a continuous chain. The follicles are almost always situated above the line of the muscularis mucosa; occasionally, however, lymphoid tissue is met with in the submucosa, but it is very rare.

A considerable number of animals were examined, in different stages of digestion and inanition, to determine whether the follicles are always present. They were always present to some degree, but they appeared to be more numerous in those animals which had been kept for some time previously on a minimum of food, or had been kept without food for two or three days. Lymphoid follicles were occasionally present in the pyloric end of the stomach. The stomachs of over forty dogs were examined, and in the greater number no follicles were noticed. Whenever in any animal these follicles were present in great numbers at the point of union of the stomach and intestine, they were also present in the stomach. The follicles in the pyloric end of the stomach are very rarely found below the line of the muscularis mucosa.

Near the point of transition between the stomach and intestine the plicæ villosæ are very short and broad, and the commencing villi are equally short and broad. But while there is thus a gradual change, from the villus-like processes of the stomach to the short villi of the commencement of the intestine, the change in the tissue is sudden. This has already been described, so far as the epithelium is concerned, but it is also true of the stroma of the mucosa. Thus, at the point of union of the stomach and intestine, we may find two elevations of the mucous membrane, one of which is covered by an epithelium, and contains a tissue similar to that found in the plicæ villosæ; the other is covered by an epithelium, and contains a tissue similar to that found in the villi.

I have examined other animals besides the dog, for the purpose of ascertaining if it be generally true that BRUNNER'S glands are anatomically continuous with the coiled tubes of the stomach.

The intestine and stomach of the horse have given perhaps the most certain proof that this is the case. In that animal the glands of the stomach are much branched, a great many coiled tubes leading into one duct. At the commencement of the intestine the coiled tubes do not, as in the dog and most other animals, become much increased in number, but pass very gradually into BRUNNER's glands. The proper tissue of the mucosa at the commencement of the intestine is very thin, and consists of minute villi and very short LIEBERKÜHN'S crypts. Further down the intestine the proper tissue of the mucous membrane increases in depth, and that part of BRUNNER'S glands which is situated above the line of the muscularis mucosa is diminished; finally, BRUNNER'S glands are only found in the submucosa. These changes are so gradual in this animal that it is very easy to trace the different steps.

In the cat the same arrangement prevails as in the dog, and there are only slight differences in the hedgehog and rabbit.

In the rat Brunner's glands begin very suddenly and are very much convoluted, while the stomach-tubes at the pylorus are short and straight. There seemed to be a difference between the epithelium of the lower part of the tubes of the pylorus and that of Brunner's glands. This difference was not met with in any other animal. In the rat I was therefore unable to trace the continuity of the stomach-tubes with Brunner's glands.

In the monkey the coiled tubes of the stomach gradually breaking through the muscularis mucosa become continuous with Brunner's glands. There are, however, certain peculiarities in the intestine of the monkey, as small valvulæ conniventes are found from its commencement. Brunner's glands are principally grouped in the submucosa of the valvulæ. In this animal the glands are so much separated that in sections it can be seen that they are not acinous, but are composed of compound tubes.

In man, sections were made from two cases obtained from the post-mortem room of persons dying after accident. It was found that the tubes of the stomach at the point of union with the intestine are placed obliquely to the line of the muscularis mucosa; they penetrate that membrane and become continuous with Brunner's glands, as has been seen to be the case in other animals.

Numerous lymphoid follicles were found at the point of union of the stomach and intestine in man, and they were found in that situation to some extent in all the animals which were examined.

This lymphoid tissue has been shown to occur in very varying amount at this point of the alimentary canal in the dog, the mucosa being sometimes almost free from it, and at other times composed in a great measure of lymphatic follicles. This latter condition was found to be the case in dogs which were kept on a very low diet. I wish to lay particular stress on these facts, as this great excess of lymphatic tissue may in itself constitute a pathological condition, and may be connected with some of those pathological changes so frequently met with in this part of the alimentary canal.

Explanation of Plates 39–43.

The outlines of many of the preparations were drawn with an Oberhaeuser's Camera Lucida: in such cases the lens used with the Camera Lucida and the approximate magnification are given. The ocular and objective which were used in completing the drawings are also given.

The preparations from which these drawings are made were hardened in chromic acid and alcohol, except where the contrary is expressly stated in the following explanations.

Fig. 1. Hartnack ocular III., objective 9, × 550.

Vertical section of part of a lymphatic follicle from the vermiform process of a rabbit. The psorospermiæ and lymph-corpuscles are seen to have invaded the epithelium.

Ps. Psorospermiæ.
Ep. Epithelium.
lc. Lymph-corpuscles.

Fig. 2. Camera Lucida: obj. 7, ×450. The drawing was completed by means of oc. III., obj. 9.

Vertical section of part of a lymphatic follicle from the vermiform process of a rabbit.

lc. Lymph-corpuscles.

Fig. 3. Oc. III., obj. 9, ×550.

Epithelial cell with two attached lymph-corpuscles, from the small intestine of a rabbit. Teased preparation which had lain twenty-four hours in one per cent. bichromate of potash, and was then treated with dilute acetic acid.

Fig. 4. Camera Lucida: obj. 8, ×600—oc. III., obj. 11 immersion.

Transverse section of epithelial cells of the surface of a villus, from the small intestine of a rabbit. The tissue had been stained in gold chloride and hardened in chromic acid.

The reticulum (*r*) is seen to surround the epithelial cells.

Fig. 5. Camera Lucida: obj. 8, ×600—oc. III., obj. 9.

Oblique section of a LIEBERKÜHN'S crypt, from the small intestine of a sheep.

r. Reticulum.
Ep. Epithelium.
e. Endothelial cells.
lc. Lymph-corpuscles.

The reticulum (*r*) is seen to send processes around the epithelial cell (*Ep*), and between the endothelial cells (*e*) of the membrana propria.

Fig. 6. Camera Lucida: obj. 8, ×600—oc. III., obj. 9.

The membrana propria of the villus with the attached blood-vessels, from a section of the small intestine of a monkey. The membrane is seen to be composed of cells; it has holes or gaps in it.

Fig. 7. Camera Lucida: obj. 5, ×300—oc. III., obj. 7.

Membrana propria of the ducts of the stomach-tubes, from a section of a dog's stomach. The appearances presented by the membrana propria of LIEBERKÜHN'S crypts are exactly similar.

Fig. 8. Camera Lucida: obj. 5, ×300—oc. III., obj. 8.

Two alveoli of the mammary gland, from a section of a mammary gland of a cat. The cells have been almost entirely shaken out of the membrana.

Gc. Remaining gland-cells.

The walls of the alveoli are composed of a framework of branching cells, united by a structureless membrane.

Fig. 9. Camera Lucida: obj. 5, × 300—oc. III., obj. 7.

Villus of the small intestine of a rabbit: teased preparation. The intestine had lain four days previously in half per cent. bichromate of potash.

The large cells composing the membrana propria are seen bordering the villus.

v. Blood-vessel.

Fig. 10. Camera Lucida: obj. 8, × 600—oc. III., obj. 11 immersion.

Section of one of the villus-like processes of a rabbit's colon. The epithelium is only drawn diagrammatically.

v. Blood-vessel cut transversely.
r. Dark line at the base of the epithelium formed by the reticulum surrounding the epithelial cells.
m. The muscle-fibres. They are seen apparently ending in the round or oval cells of the membrana propria.

Fig. 11. Camera Lucida: obj. 7, × 450—oc. III., obj. 8.

Section of one of the villus-like processes of a rabbit's colon.

m. A muscle-fibre.
r. Reticulum.
e. Endothelial cells of the membrana propria.

Fig. 12. Camera Lucida: obj. 5, × 300—oc. III., obj. 8.

Cross section of the muscularis mucosæ, from the rectum of a sheep.

The reticulum is seen to surround the individual fibres.

Fig. 13. Oc. III., obj. 8, × 400.

Section of a villus, from the small intestine of a monkey.

m. A band of involuntary muscle-fibres. The connective-tissue reticulum surrounding the individual fibres is attached to the membrana propria.
Ep. Epithelium. The epithelial cells are seen to be of different lengths.
r. Dark line at the base of the epithelial cells caused by the reticulum.
lc. Lymph-corpuscle.
e. Endothelial cells of the membrana.
v. Blood-vessels.

The great similarity of the cells of the villus to the cells composing the membrana is seen.

Fig. 14. Oc. III., obj. 9, × 550.

Section of the upper part of a villus, from the small intestine of a monkey.

m. Muscle-fibres.

l. Central chyle-vessel.

v. Blood-vessels.

Fig. 15. Camera Lucida: obj. 8, ×600—oc. III., obj. 9.

Artery, from a vertical section of a villus from the small intestine of a hedgehog.

The reticulum is seen as a dark line surrounding the individual muscle-fibres.

c. Cells of the villus.

Fig. 16. Camera Lucida: obj. 8, ×600—oc. III., obj. 9.

Artery, from a vertical section of a villus from the small intestine of a hedgehog.

The muscle-fibres surrounding the vessel only occur at rare intervals. The reticulum (*r*) is seen as a dark line surrounding the individual fibres, and, where these muscle-fibres are wanting, the reticulum forms an adventitia to the vessel.

The elongated nuclei of the endothelial cells are seen.

Fig. 17. Camera Lucida: obj. 8, ×600—oc. III., obj. 9.

Vessel, probably an artery, from a section of a villus of the duodenum of a rat.

The reticulum forms an adventitia to the vessel.

Fig. 18. Camera Lucida: obj. 8, ×600—oc. III., obj. 9.

Vein, from a section of a villus of the duodenum of a rabbit. The reticulum forms an adventitia to the vessel, and passes between the cells of the villus.

Fig. 19. Camera Lucida: obj. 7, ×450—oc. III., obj. 9.

Vertical section of the lower part of a villus, from the small intestine of a monkey, showing a large vein.

me. Section of the membrana propria.

v. Capillary blood-vessel.

r. Reticulum.

The endothelial cells of the vein are seen to be surrounded by a very delicate reticulum.

There is great similarity between the cells of the villus and the endothelium of the vein.

Fig. 20. Camera Lucida: obj. 5, ×300—oc. III., obj. 8.

Section of a narrow villus, from the duodenum of a rat.

ep. Surface of the epithelium.

v. Capillary blood-vessels.

A reticulum is seen between the endothelial cells of the chyle-vessel (*l*).

Fig. 21. Camera Lucida: obj. 7, ×450—oc. III., obj. 9.

Section of a villus, from the commencement of the duodenum of a dog.

l. The central chyle-vessel.

m. Bands of involuntary muscle-fibres.

lc. Lymph-corpuscle.

v. Blood-vessels.

In the upper part of the chyle-vessel, the reticulum surrounding the cells of the villus is seen to be continued between the endothelial cells of the chyle-vessel.

The cells of the upper part of the villus are larger than those in the lower part.

In the lower part of the figure the reticulum can be traced from the chyle-vessel to the border of the villus.

Fig. 22. Camera Lucida: obj. 7, × 450—oc. III., obj. 9.

Section of the lower part of a villus, from the small intestine of a hedgehog.

l. Central chyle-vessel, containing a little granular matter.

m. A small band of muscles; they are in contiguity with the wall of the chyle-vessel.

The reticulum is attached to the wall of the chyle-vessel, and passes between the cells of the villus.

Figs. 23, 24, & 25. From the villi of a hedgehog killed during absorption of fat. The intestine was hardened in osmic acid.

Fig. 23. Oc. III., obj. 11 immersion, × 850.

Surface view of epithelium, teased, and treated with caustic potash.

The fat is seen as small black particles between the epithelial cells. The clear spaces are the openings of goblet-cells.

Fig. 24. Camera Lucida: obj. 8, × 600—oc. III., obj. 9.

Section of a villus. The fat is seen as small black granules in a reticulum.

Fig. 25. Camera Lucida: obj. 7, × 450—oc. III., obj. 8.

Section of the lower part of a villus.

l. Chyle-vessel.

In the upper part of the figure the fat-particles in the chyle-vessel have run together.

The fat-particles are seen in the reticulum of the villus.

Fig. 26. Oc. III., obj. 2, × 45.

Vertical section of the pyloric end of the stomach of a dog.

mm. Muscularis mucosæ.

d. Duct of the tubes.

ct. Proper glands, or coiled tubes.

Some of the plicæ villosæ (*p*) are seen to be shorter than the others; the epithelium on the sides of the shorter ones is folded.

Fig. 27. Camera Lucida: obj. 5, × 300—oc. III., obj. 7.

Epithelium covering one of the villus-like processes of a rabbit's colon.

The intestine had been stained in gold and hardened in chromic acid.

The nuclei of the epithelial cells are seen to be divided transversely, obliquely, and vertically.

Fig. 28. Oc. III., obj. 7, × 300.

Section of one of the plicæ villosæ from the stomach of a dog. The animal was killed two hours after food.

lc. Lymph-corpuscles.

Fig. 29. Camera Lucida: obj. 7, × 450—oc. III., obj. 8.

Epithelial cells covering one of the plicæ villosæ, from a section of the stomach of a dog.

The mucus in the upper part of the epithelial cells is very deeply stained. At the base of the epithelium numerous small round or conical cells are seen.

Fig. 30. Camera Lucida: obj. 5, × 300—oc. III., obj. 8.

Epithelium covering the plicæ villosæ: from a section of the stomach of a dog.

The stomach had been stained in gold and hardened in chromic acid.

b. Broad cells with nuclei in a state of division.

Fig. 31. Camera Lucida: obj. 5, × 300—oc. III., obj. 8.

Epithelium covering the plicæ villosæ: from a section of the stomach of a dog, showing a small bud-like group of cells.

Fig. 32. Camera Lucida: obj. 5, × 300—oc. III., obj. 8.

Oblique section of epithelium covering the plicæ villosæ: from the stomach of a dog.

b. Pale cells with spherical nuclei.

Fig. 33. Camera Lucida: obj. 5, × 300—oc. III., obj. 8.

Section of a short villus-like process: from the stomach of a dog, showing the "epithelial buds."

The nuclei of the cells composing the bud-like groups are spherical, and are less stained than those of the neighbouring cells.

Fig. 34. Camera Lucida: obj. 5, × 300—oc. III., obj. 8.

Two of the villus-like processes of the pyloric end of the stomach of a frog (*Rana esculenta*). Only part of the figure is filled in.

v. Blood-vessels at the summits of the processes.

On the left side of the figure the great length of the epithelial cells is seen.

Fig. 35. Camera Lucida: obj. 8, × 600—oc. III., obj. 11 immersion.

Slightly oblique section of the epithelium of the ducts of the stomach-tubes: from the stomach of a dog.

The reticulum is seen to surround the epithelial cells.

Fig. 36. Camera Lucida: obj. 8, × 600—oc. III., obj. 11 immersion.

Vertical section of the upper part of one of the plicæ villosæ, from the stomach of a dog.

The epithelium is diagrammatic.

A clear space is seen to contain a blood-vessel (*v*).

The upper wall of the clear space is formed by the endothelial cells (*e*) of the membrana propria.

e'. Endothelial cells forming the lower wall of the perivascular space.

m. The muscle-fibres: in the lower part of the figure they form a membranous covering to the endothelial cells.

One of the muscles ends by being apparently attached to an endothelial cell (*e*). Compare fig. 10.

Fig. 37. Camera Lucida: obj. 5, × 300—oc. III., obj. 8.

Surface view of one of the terminal alveoli of the proper gland-tubes, from the pyloric end of the stomach of a dog; the animal was killed two hours after meat food.

A delicate reticulum is seen surrounding the epithelial cells.

Fig. 38. Camera Lucida: obj. 5, × 300—oc. III., obj. 8.

Cross section of one of the terminal alveoli of the proper gland-tubes, from the pyloric end of the stomach of a dog; the animal was killed while fasting.

me. Membrana propria.

a. The faintly granular gland-cells with a dark line at their base.

b. The epithelial cells are cut obliquely; the nuclei are partly seen to the inner side of the dark line.

Fig. 39. Camera Lucida: obj. 5, × 300—oc. III., obj. 8.

Oblique section of one of the terminal alveoli of the proper gland-tubes; from the pyloric end of the stomach of a dog; the animal was killed two hours after meat food.

me. Membrana propria.

The nuclei and the reticulum are both clearly seen.

Fig. 40. Camera Lucida: obj. 5, × 300—oc. III., obj. 8.

Vertical section of epithelial cells of one of the terminal alveoli of the proper gland-tubes, from the pyloric end of the stomach of a dog killed five hours after meat food.

b. Two cells whose nuclei are in a state of vacuolation; the other cells have spherical nuclei.

Fig. 41. Camera Lucida: obj. 5, ×300—oc. III., obj. 8.

Section of one of the terminal alveoli of the proper gland-tubes, from the pyloric end of the stomach of a dog. The stomach had been hardened in osmic acid and subsequently in chromic acid.

The reticulum has a double outline, and is much broader than in fig. 37 or fig. 38.

Fig. 42. Camera Lucida: obj. 8, × 600 nearly—oc. III., obj. 9.

Vertical section of the upper part of one of the plicæ villosæ; from the stomach of a dog.

The epithelium is drawn diagrammatically.

v. Blood-vessel.
m. Muscle-fibres.
e. Endothelial cells.

The disposition of the muscle-fibres and the perivascular spaces are well seen.

Fig. 43. × 20 times nearly. Vertical longitudinal section of the point of transition of the stomach and intestine of a dog. This drawing was made from two specimens, and is therefore slightly diagrammatic.

M. Part of the muscular wall.
SM. Submucosa.
mm. Muscularis mucosa.
lc. Lymphatic follicles.

The coiled tubes are seen to break through the line of the muscularis mucosa and become continuous with the glands lying in the submucosa (BRUNNER's glands).

The ducts of two lobes of BRUNNER's glands are seen between the crypts of LIEBERKÜHN.—I have to thank my friend Mr. HOPE, of St. George's Hospital, for this drawing.

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XIX. *The Residual Charge of the Leyden Jar. By* J. Hopkinson, *M.A., D.Sc. Communicated by Sir* William Thomson, *F.R.S., Professor of Natural Philosophy in the University of Glasgow.*

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1. Suppose that the state of a dielectric under electric force* is somewhat analogous to that of a magnet, that each small portion of its substance is in an electropolar state. Whatever be the ultimate physical nature of this polarity, whether it arises from conduction, the dielectric being supposed heterogeneous (see Maxwell's 'Electricity and Magnetism,' vol. i. arts. 328–330), or from a permanent polarity of the molecules analogous to that assumed in Weber's theory of induced magnetism, the potential at points external to the substance due to this electropolar state will be exactly the same as that due to a surface distribution of electricity, and its effect at all external points may be masked by a contrary surface distribution. Assume, further, that dielectrics have a property analogous to coercive force in magnetism, that the polar state does not instantly attain its full value under electric force, but requires time for development and also for complete disappearance when the force ceases. The residual charge may be explained by that part of the polarization into which time sensibly enters. A condenser is charged for a time, the dielectric gradually becomes polarized; on discharge the two surfaces of the condenser can only take the same potential if a portion of the charge remain sufficient to cancel the potential, at each surface, of the polarization of the dielectric. The condenser is insulated, the force through the dielectric is insufficient to permanently sustain the polarization, which therefore slowly decays; the potentials of the polarized dielectric and of the surface charge of electricity are no longer equal, the difference is the measurable potential of the residual or return charge at the time. It is only necessary to assume a relation between the electric force, the polarization measured by the equivalent surface distribution, and the time. For small charges a possible law may be the following:—For any intensity of force there is a value of the polarization proportional to the force to which the actual polarization approaches at a rate proportional to its difference therefrom. Or we might simply assume that the difference of potentials E of the two surfaces and the polarization are connected with the time by two linear differential equations of the first order. If this be so, E can be expressed in terms of the time t during insulation by the formula $E=(A+B\varepsilon^{-\mu t})\varepsilon^{-\lambda t}$, where λ and μ

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* To define the electric force within the dielectric it is necessary to suppose a small hollow space excavated about the point considered; the force will depend on the form of this space; but it is not necessary for the present purpose to decide what form it is most appropriate to assume.

are constants for the material, and A and B are constants dependent on the state of the dielectric previous to insulation. It should be remarked that λ does not depend alone on the conductivity and specific inductive capacity, as ordinarily determined, of the material, but also on the constants connecting polarization with electric force. Indeed if the above view really represent the facts, the conductivity of a dielectric determined from the steady flow of electricity through it measured by the galvanometer will differ from that determined by the rate of loss of charge of the condenser when insulated.

2. A Florence flask nearly 4 inches in diameter was carefully cleansed, filled with strong sulphuric acid, and immersed in water to the shoulder. Platinum wires were dipped in the two fluids, and were also connected with the two principal electrodes of the quadrant electrometer. The jar was slightly charged and insulated, and the potentials read off from time to time. It was found (1) that even after twenty-four hours the percentage of loss per hour continued to decrease, (2) that the potential could not be expressed as a function of the time by two exponential terms. But the latter fact was more clearly shown by the rate of development of the residual charge after different periods of discharge, which put it beyond doubt that if the potential is properly expressed by a series of exponential terms at all, several such terms will be required.

The following roughly illustrates how such terms could arise. Glass may be regarded as a mixture of a variety of different silicates; each of these may behave differently under electric force, some rapidly approaching the limiting polarity corresponding to the force, others more slowly. If these polarities be assumed to be n in number, they and E may be connected with the time by $n+1$ linear differential equations. Hence uring insulation E would be expressed in the form $\Sigma_0^n A_r \varepsilon^{-\lambda_r t}$. Suppose now a condenser be charged positively for a long time, the polarization of all the substances will be fully developed; let the charge be next negative for a shorter time, the rapidly changing polarities will change their sign, but the time is insufficient to reverse those which are more sluggish. Let the condenser be then discharged and insulated, the rapid polarizations will decay, first liberating a negative charge; but after a time the effect of the slow terms will make itself felt and the residual charge becomes positive, rises to a maximum, and then decays by conduction. This inference from these hypotheses and the form of the curve connecting E with t for a simple case of return charge is verified in the following experiments.

3. A flask was immersed* in and filled with acid to the shoulder. Platinum electrodes communicated with the electrometer as before. The flask was strongly charged positive at 5.30 and kept charged till 6.30, then discharged till 7.8 and negatively charged till 7.15, when it was discharged and insulated. The potential was read off at intervals till 8.20. The abscissæ of curve A (Plate 44) represent the time from insulation, the ordinates the corresponding potentials, positive potentials being measured upwards. It will be seen that a considerable negative charge first appeared, attaining a maximum in about five

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* Acid on both sides of the dielectric, that there might be no electromotive force from the action of acid on water either through or over the surface of the glass.

minutes; it then decreased, and the potential was *nil* in half an hour; the main positive return charge then came out, and was still rapidly increasing at 8.20, when the flask was again discharged. At 8.39 the same flask was charged negatively till 8.44, then discharged and charged positively for 45 seconds, insulated 15 seconds and discharged, and finally insulated at 8.45. Curve B (Plate 44) represents the subsequent potentials. It is seen that the return charge twice changes sign before it assumes its final character. The experiment was several times repeated with similar results.

Sir WILLIAM THOMSON has informed the author, since these experiments were tried, that he himself performed similar experiments many years ago, and showed them as lecture illustrations in his Class in the University of Glasgow, but never otherwise published them, proving that the charges come out of the glass in the inverse order to that in which they go in[†].

4. When steel is placed in a magnetic field, mechanical agitation accelerates the rapidity with which its magnetic polarity is developed. Again, vibration reduces the magnetism of a magnet, or, so to speak, shakes its magnetism out. This would suggest, on the present hypothesis, that vibration would accelerate changes in the electric polarity of a dielectric, or shake down polarization and liberate residual charge. The following experiments verify this anticipation. The arrangement was as in (3). The flask was strongly charged for some hours, discharged at 4.45 P.M., and kept with the two coatings connected by a platinum wire, except for a few moments at a time, to ascertain the rate at which the polarization was decaying, till 9.48, when the flask was insulated and the number of seconds observed in which the potential rose to 100, 200, 300, and 500 divisions of the scale of the quadrant electrometer, every thing being as steady as possible. The flask was then discharged, again insulated at 10.18, and the development of the charge observed, the neck of the flask being sharply tapped during the whole time. The experiment was repeated quiet at 10.48, with tapping at 11.16. Column I. gives the time of beginning the observation, II., III., IV., and V. the number of seconds in which charges 100, 200, 300, 500 developed respectively. The periods of tapping are marked with an asterisk.

I.	II.	III.	IV.	V.
9.48	118	240	367	624
10.18	80*	140*	185*	320*
10.48	140	285	440	750
11.16	120*	210*	310*	540*

The effect may appear small; but it must be remembered that, the flask containing and being immersed in sulphuric acid to the shoulder, the vibration caused by tapping the neck could be but small, and could scarcely penetrate to the lower part of the flask. The experiment was subsequently repeated with the same flask and with a similar result; but it was further found that the effect of tapping was more marked when the periods during which the flask was strongly charged and discharged were long than when they were short. For example, when the flask was charged half an hour, then discharged five minutes, the effect of tapping was very slight although unmistakable. That portion of the return charge which comes out slowly is more accelerated by vibration than that which comes out fast. A comparison of the rates at 10.18 and 11.16 of the above Table also shows that a flask which has been tapped is less susceptible to the effect of tapping than it was before it was touched. In some cases also it was noticed that if three observations were made, the first quiet, the second tapped, and the third quiet, the third charge came out more rapidly than the first. The last experiment on tapping below illustrates both of these points.

[†] These results are closely analogous to those obtained by BOLTZMANN for torsion (Sitzungsberichte der k. Akad. der Wiss. zu Wien, Bd. lxx. Sitzung 8. Oct. 1874). From his formulæ it follows that if a fibre of glass is twisted for a long time in one direction, for a shorter time in the opposite direction, and is then released, the set of the fibre will for a time follow the last twist, will decrease, and finally take the sign of the first twist.

A flask was mounted as before, strongly charged at 12 o'clock, discharged at 3, and remained discharged till 5.15, when it was insulated, and the time which the image took to traverse 200 divisions was noted; after passing that point the flask was again discharged. The first column gives the instant of insulation, the second the time of covering 200 divisions. The observations without mark were made with the flask untouched, in those marked * it was sharply tapped all over with a glass rod dipping in the acid, whilst in those marked † the rod was muffled with a piece of india-rubber tubing.

	Time of insulation.		Time occupied in traversing 200 divisions of the scale.	
	h	m	min.	secs.
	5	15	1	23
	5	18	1	23
	*5	21		40
	5	24	1	17
	†5	27		48
	5	30	1	27
Remained discharged till	5	46½	1	25
	†5	49½		54
	5	51½	1	24
	*5	54	1	3
	5	56	1	24
Remained discharged till	6	39	2	7½
	*6	43	1	54
	6	47	2	8
	†6	51	2	2
	6	55	2	13

	Time of insulation. h	Time of insulation. m	Time of traversing 100 divisions. min.	Time of traversing 100 divisions. secs.
Remained discharged till	8	51	2	11
	†8	55		57
	8	58	2	12
	*9	2	1	2
	9	5	2	14
	†9	9		54
	9	12	2	17

The same flask was strongly charged at 9.15 in the evening and discharged at 9 the following morning, and remained so till 7.13 in the evening, when the following observations of the time of traversing 100 divisions were made:—

Time of insulation. h	Time of insulation. m	Time occupied in traversing 100 divisions of the scale. min.	Time occupied in traversing 100 divisions of the scale. secs.
7	13	2	43
†7	18	1	35
7	21	2	35
*7	25	1	53
7	28	2	27
†7	32	1	46
7	35	2	26
*7	39	1	49
7	43	2	25

The result here was less than the author expected, considering the long period of discharge and the considerable effect obtained in the previous experiment; this may perhaps be due to change of temperature, or perhaps to a difference in the vigour with which the flask was tapped‡.

5. When a charge is given to an insulated flask, owing to polarization the percentage of loss per minute continuously diminishes towards a limiting value. When the flask is charged, discharged, and insulated, one would expect that after attaining a maximum potential the rate of loss would steadily *increase* towards the same limiting value as in the former case. The following experiment shows that this is not always the case.

A flask of window-glass, much more conductive than the Florence flask, was mounted as in (3) and (4). It was charged, and the charge maintained for three quarters of an hour, then discharged for a quarter of an hour, and insulated. In four minutes the charge attained a maximum value 740. In fifteen minutes the potential was 425, in twenty minutes 316, giving a loss in five minutes of 26 per cent. In thirty minutes it was 186, and in thirty-five minutes 146, a loss of $21\frac{1}{2}$ per cent. The intermediate and subsequent readings of the same series showed a steady decrease to as little as 15 per cent. The experiment was repeated with the same flask, but with shorter periods of discharge and with a similar result.

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‡ It is recorded by Dr. Young that an electical jar may be discharged either by heating it or by causing it to sound by the friction of the finger.

6. Although the above view is only proposed as a provisional working hypothesis, some suggestions which it indicates may be pointed out.

Temperature has three effects on the magnetic state of iron or steel:—(1) Changes of temperature cause temporary changes in the intensity of a magnet; (2) temperature affects the "permeability" of a magnet; at a red heat iron is no longer sensibly magnetic; (3) a rise of temperature reduces coercive force.

It may be expected that the polarity of dielectrics may also be affected in three analogous ways:—(1) a sudden change of temperature might directly and suddenly affect the polarity (an example of this we have in the phenomena of pyro-electricity); (2) the constant expressing the ratio of limiting polarity to electromotive force may depend on temperature; and (3) temperature may alter the constant, expressing the rate at which polarity approaches its limiting value for a given force, as it is known to alter the specific conductivity. Mr. PERRY'S experiments show that temperature does affect the polarization of dielectrics, but in which way does not appear.

Sir WILLIAM THOMSON (papers on Electrostatics and Magnetism, art. 43) explains specific inductive capacity by a polarization of the dielectric following the same formal laws as magnetism. It is only necessary to introduce time into that explanation as here proposed to enable it to cover the phenomena of residual charge. Again (see NICHOL'S Cyclopædia), Sir W. THOMSON explains the phenomena of pyro-electricity by supposing that every part of the crystal of tourmaline is electropolar, that temperature changes the intensity of its polarity, and that this polarity is masked by a surface distribution of electricity supplied by conduction over the surface or otherwise. We have, then, in tourmaline an analogue to a rigidly magnetized body, in glass or other dielectrics analogues to iron having more or less coercive force.

XX. *On the Physiological Action of Vanadium.* *By* JOHN PRIESTLEY, *Platt Physiological Scholar at Owens College, Manchester.* *Communicated by Professor* ARTHUR GAMGEE, *F.R.S.*

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I. INTRODUCTION.

THE investigation, of which the results are recorded in the following pages, was carried out in the Physiological Laboratory of the Owens College, at the suggestion and under the direction of Professor ARTHUR GAMGEE.

The elaborate investigations of ROSCOE had placed vanadium amongst the metals whose chemical characters and relations have been rigidly investigated; they had shown that vanadium is to be ranked as a member of one of the most interesting families of elements, and yet not a single fact had been ascertained in reference to its physiological action. The hope that an elaborate examination of the physiological reactions of vanadium might cast some light upon the relations which may exist between the chemical and the physiological affinities of elements, and the fact that Professor Roscoe offered to furnish any vanadium compound which might be required, acted as inducements to undertake this research.

Vanadium belongs to the group of pentad elements, which includes nitrogen, phosphorus, arsenic, antimony, and bismuth. It would obviously be out of place here to examine in detail the grounds upon which this relationship of vanadium has been based—as, for example, the analogies between the oxides of nitrogen and vanadium; the resemblance of phosphates, arseniates, and vanadates; the isomorphism of vanadinite and pyromorphite, &c.

A glance at the atomic weights of the chief members of the arsenic group of elements shows that vanadium has an atomic weight which places it between phosphorus and arsenic:—

N, Nitrogen	14
P, Phosphorus	31
V, Vanadium	51·2
As, Arsenic	75
Sb, Antimony	122
Bi, Bismuth	210

The fact that, in a family of which several members exert a highly poisonous action, a new metal could be found whose atomic weight was nearly the mean of that of the two members possessing the greatest toxicological interest appeared to render the research an important one; and the interest was enhanced by the fact that vanadium possesses an atomic weight very nearly the same as that of a poisonous metal not belonging to the arsenic group, but whose compounds bear some resemblance to those of vanadium, viz. chromium:—

Atomic weight of chromium	52·2
,, vanadium	51·2

Vanadium forms four series of compounds. First, a pentad series, of which vanadic oxide, V_2O_5, may be taken as a representative; this oxide forms soluble vanadates with the alkaline metals. Secondly, a series of hypovanadic compounds, represented by a tetrachloride, VCl_4, and by hypovanadic oxide, V_2O_4. Thirdly, a triad, vanadous series, of which may be taken as a representative the trichloride, VCl_3, analogous to the arsenic and antimony compounds, but, unlike them, non-volatile. Fourthly, a diad, hypovanadous series, represented by VCl_2 and V_2O_2 (hypovanadous oxide).

Although it appeared desirable to investigate bodies belonging to the various groups of vanadium compounds, it was found expedient to restrict the investigation to the sodium compound of vanadic acid. The reasons for not examining the action of the lower oxides, or of the compounds analogous to them, were :—First, that definite solutions could not be obtained in such a condition as to admit of their being suitably introduced into the animal organism; this remark will be understood when it is stated that no useful results can be obtained from experiments in which a very alkaline or a very acid solution, capable of at once altering the chemical and physical properties of the blood, is introduced into that fluid. Second, that the lower oxides of vanadium are so extremely unstable as to render any experiments with them very difficult of interpretation. Fortunately we may, with reason, conclude that an elaborate investigation into the mode of action of any soluble vanadate will fairly represent the physiological action of the vanadium compounds generally; for although the lethal doses may be, and often are, different, the physiological properties of any of the inorganic compounds of a poisonous metal appear to be similar, whatever the nature of the compound.

The salt used in this research was the tribasic sodium vanadate (Na_3VO_4), obtained by fusing a mixture of three molecules of sodium carbonate with one molecule of vanadium pentoxide until no further evolution of carbonic acid occurred. The tribasic sodium vanadate resulting from this operation is a white crystalline mass, easily soluble in water. The solution employed throughout this research contained exactly five per cent. of V_2O_5. In order to avoid any accidental presence of sodium carbonate which might exert an injurious action on the blood of the animal experimented upon, a stream of CO_2 was passed through the concentrated solution of the sodium salt before it was diluted so as to have the required strength. The solutions employed were prepared from time to time in the Chemical Laboratory of the Owens College, under the supervision of Professor Roscoe.

In this paper the mode of action of vanadium on simple organisms and on animals of different classes will be described, and then the experiments which illustrate its more precise influence on the various functions of the body will be given in detail.

It was originally intended to institute in this memoir a comparison between the action of vanadium and that of the allied metals of the same family. However, we do not yet possess sufficiently elaborate accounts of the precise physiological action of these metals, so that further investigations are necessary before such a comparison can be usefully instituted. Such an investigation is now in progress in the Physiological Laboratory of the Owens College. A research which the author has lately carried out on the physiological action of chromium appears to prove most conclusively that this metal, whose atomic weight, as was just mentioned, is almost identical with that of vanadium, exerts an altogether different physiological action and possesses a less intense poisonous activity.

II. EFFECTS ON SIMPLE ORGANISMS.

A few preliminary experiments were undertaken to determine the effects of sodium vanadate upon *Bacteria*, germinating seed and fungi, and infusorians.

Experiment I.—December 12, 1873.

A ·5 per cent. solution of sodium vanadate does not prevent the development of *Bacteria.*

Exp. II.—May 14, 1874.

Mustard-seeds and lettuce-seeds were set to grow on pieces of flannel moistened with solutions of sodium vanadate of strengths varying from 1 per cent. to ·01 per cent. (the amount of V_2O_5 in the solutions being referred to in all cases), and compared with similar seeds set to grow on flannels moistened with distilled water.

When the experiments were at an end the vessels containing the flannels still moistened with the same solutions were allowed to stand for several days. Mould appeared in certain of the vessels only, viz. in those containing distilled water or solutions of the salt of vanadium of slight strength.

From these experiments it appears that germination is not prevented, although it may be slightly interfered with, by the presence of sodium vanadate in solutions of ·1 per cent. or less, but that it is totally prevented in solutions of 1 per cent.

The same remarks apply to fungi.

Exp. IV.—September 1874.

An infusion of cabbage-leaves was allowed to develop infusorians by being kept in a warm place.

Drops of the infusion were treated, while under observation beneath the microscope, with solutions of sodium vanadate.

From this experiment it appears that even dilute solutions of sodium vanadate (solutions containing ·01 per cent. of V_2O_5) cause an immediate disturbance of vital function in infusorians.

III. EFFECTS ON COMPLEX ORGANISMS.

A. General Action on the Animal System.

Certain preliminary experiments were made to determine the reactions between the vanadium salt used and some of the fluids and juices of the body with which it must come into contact in its passage through the system. The results were as follows:—

1st. Vanadate of soda does not affect the optical properties of blood.

2nd. No reduction of the vanadic salt takes place on treatment with peptones or saliva, or on treatment with starch-mucilage or fats.

These preliminaries having been settled, the effects of sodium vanadate upon the animal system were determined after the introduction of the poison by various ways.

i. *Action of the Poison when introduced into the System by subcutaneous injection.*

On Frogs.

Exp. VII.—December 3, 1873.

Weight 24 grms.

Dose ·5 cub. centim. of the 5 per cent. solution (25 milligrammes V_2O_5), injected under the skin of the back.

h. m.

2 25. Injection complete: frog very active.

3 0. Normal to all appearance, and active.

3 10. Not so active, but otherwise normal.

3 15. Quieter.

3 20. Still moves limbs freely; no signs of paralysis.

3 25. Conscious; respiration has ceased.

3 35. Quiet; moves on being irritated. Conscious; lower jaw has fallen. No breathing at the lungs.

3 40. Lower jaw has sunk more; moves on being irritated; still not breathing.

3 55. Cornea sensitive; attempts to move when stirred.

4 15. Still capable of moving.

5 0. On being stirred the frog makes vigorous efforts to leap, but does not seem able to grasp the table firmly enough, although its muscular contractions are sufficiently energetic.

5 50. Nearly dead; does not retract its limbs after they have been spread out, as it did some time previously; still attempts to move a little when stimulated.

6 5. No movement at all on being irritated.

The frog was then opened; the heart was contracting perfectly.

Liver very dark in colour.

Muscular and nervous irritability quite normal on applying electrical stimulation. On snipping through the cord the legs were observed to contract.

In this experiment it may be noticed that complete paralysis of voluntary muscles occurred in 3 hours 40 minutes after injection; that the poison began manifestly to act within 1 hour of injection; that the respiratory muscles were the first to cease acting; that consciousness remained for some hours after respiration had ceased; that the heart was not affected; that muscular and nervous irritability remained perfect on direct stimulation by induction-currents; and that the cord seemed capable of *conducting* stimuli.

Exp. VIII.—January 21, 1874.

Weight (a small English frog).

Dose 1 cub. centim. of a ·5 per cent. solution prepared from the ordinary 5 per cent. solution (*i. e.* 5 milligrammes V_2O_5), injected under the skin of the back.

Note.—A small amount was lost during injection.

In this experiment 5 milligrammes of V_2O_5 caused death in a frog within 36 hours. The noteworthy points are that a gradual and general paralysis occurred, that the intestinal tract was congested, and that it contained a greenish mucus.

Exp. IX.—February 20, 1874.

Weight 24·5 grms. (English frog).

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes V_2O_5), injected under the skin of the back.

From this experiment we learn that paralysis appeared within 40 minutes of the time of injection, that the heart was so affected as to die on exposure sooner than an unpoisoned heart would probably have done, that the irritability of voluntary muscles and of motor nerves was unimpaired.

Exp. X.—February 20, 1874.

Weight 29 grms.

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes V_2O_5), injected under the skin of the back.

Note.—A certain amount of the solution escaped during injection.

This experiment serves to corroborate the preceding.

Exp. XI.—May 27, 1874.

Weight 29 grms.

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes V_2O_5), injected under the skin of the back.

This experiment shows that vanadium-poisoning causes paralysis of respiration, general paralysis of voluntary muscles, injury to the power of reflex activity, without affecting muscle, nerve, or *conducting-power* of cord directly.

On a Pigeon.

Exp. XII.—February 25, 1874.

The pigeon was healthy and rather young.

Dose ·5 cub. centim. of the 5 per cent. solution (25 milligrammes V_2O_5), injected under the skin of the breast.

h. m.	
3 47.	Injection complete.
4 30.	Quiet, but otherwise normal.
5 15.	Discharge of fæces, green in colour.
6 10.	Further discharge of fæcal matter, which is now of a red colour and very watery, containing blood-corpuscles and epithelial cells.
6 30.	Further discharge of sanguineous fluid fæces.
9 48.	Sanguineous fæcal discharges have continued in the meantime.

Body sprawls; legs appear to be paralyzed, as also the whole body; gasping, beak open; eye insensitive.

The pigeon must have died soon after. The *post mortem* examination was not made until 10.30 the following morning.

Post mortem Examination.

On cutting through the skin over the throat dark maroon-coloured extravasations were noticed. Heart slightly distended.

Liver normal, or perhaps slightly congested.

Pancreas normal.

Œsophagus above the gizzard is filled with a green fluid matter and is also congested. Duodenum for 1 inch below the gizzard is much congested. The congestion then suddenly ceases (just where the pancreas is situated), but recommences about 2 inches lower down with great intensity. At this point the intestine becomes filled with brown mucous contents containing blood-corpuscles, epithelial cells, and granular bodies. The congestion becomes less marked as the intestine is traced towards the rectum, but increases again in the latter division of the alimentary tract. The crop is not markedly congested and is empty; the œsophagus below it is filled with green mucous contents.

Gizzard normal.

In this experiment we notice that the poison began manifestly to act within 2 hours 15 minutes of the time of injection; that the first symptoms were drowsiness, and an action on the alimentary canal as indicated by the sanguineous fluid fæces; that finally paralysis of motion occurred; that the alimentary canal was intensely congested in portions; that the lower portion was filled with brownish contents containing blood-corpuscles.

On Guineapigs.

Exp. XIII.—December 3, 1873.

Weight 632 grms.

Dose 2 cubic centims. of the 5 per cent. solution (100 milligrammes V_2O_5), injected under the skin of the back.

h. m.

2 25. Injection completed.

Quiet; seemed inclined to eat; but did not take the green food presented to it.

2 30. Appears quite normal and at ease.

2 45. Not quite so lively; does not stir when the hand is placed near it; manifests desire to hide itself beneath the hay in the observation-chamber.

2 50. Quiet, but otherwise normal.

3 0. Evinces great desire to hide itself under the hay or in a corner. Is indisposed

to stir when touched or moved. Walks with difficulty. Lies down on stomach. Appears paralytic. Frequent twitches, especially of the hind legs and head.

h. m.

3 10. Breathes by jerks. Spasmodic twitches of limbs.

3 15. Breathing not so rapid; frequent convulsions of legs and head and of the whole body.

Breathes in spasmodic gasps. Eyelids close only after repeated irritation of cornea.

3 25. Breathes in gasps; the convulsions have ceased.

3 30. Breathing shorter and more rapid. Is not so quiet as before. Cornea seems rather more sensitive. Breathing less violent.

3 40. Sensibility more perfect. Breathing rapid, but regular. Lies in normal position of health and not on its side as before. No convulsions have been noticed.

3 45. Breathing regular; attempts to move, but it is with difficulty, and a tendency to a return of the convulsive symptoms.

4 0. Breathing slight; occasional twitches.

4 15. Tries to move; the convulsive twitchings seem to be returning in strength.

5 0. Breathing irregular and at lengthened intervals.

On lifting the animal on to a table its fore and hind limbs became convulsed.

After lying for about 5 minutes, breathing at long intervals in feeble gasps, it died.

Post mortem Examination.

The blood coagulated normally.

The right heart distended. Ventricles contractile on irritation.

Liver apparently normal.

Stomach distended with food; exhibited punctiform, hæmorrhagic extravasations on the internal surface, chiefly at the vertebral aspect and cardiac end.

Duodenum normal.

Rectum perhaps slightly congested.

Blood taken from left ventricle diluted with water and placed before the slit of a spectroscope exhibited the normal oxyhæmoglobin bands. After standing two days the blood solution still appeared quite normal. On adding some of STOKES's reagent the band of reduced, or oxygen-free, hæmoglobin appeared, and was again replaced by the two oxyhæmoglobin lines on shaking up the solution with air.

This experiment shows that 100 milligrammes (about) of $V_2 O_5$ produced death in 2 hours 35 minutes; that symptoms appeared within 35 minutes of the time of injection; that the symptoms of poisoning were quiescence, paralysis, alternating with convulsions of the limbs and head; spasmodic respirations, the inspirations being shallow and rapid (as in peritonitis); possibly an impairment of sensibility; *post mortem* appearances of congestion of the alimentary mucous membrane, with blood-extravasations. The blood was uninjured by the poison as far as its optical properties indicated.

Exp. XIV.—January 14, 1874.

Weight 595 grms.

Dose 2 cub. centims. of the 5 per cent. solution (100 milligrammes V_2O_5), injected under the skin.

This experiment shows that 100 milligrammes of V_2O_5 produced death in 3 hours 25 minutes; that symptoms of poisoning appeared within eight minutes of the time of injection; that the chief symptoms were drowsiness, a convulsive movement of the limbs, head, and body, with general weakness or inability to move easily; that sensation appeared unimpaired; and that respiration became difficult towards the close of the experiment. After death the alimentary canal appeared to have suffered slight but distinct congestion in portions, and the lungs were also congested.

Exp. XV.—January 21, 1874.

Weight 755 grms.

Dose ·5 cub. centim. of the 5 per cent. solution (25 milligrammes V_2O_5), injected under the skin of the right shoulder.

h. m.

8 51. Injection complete.

9 10. Very uneasy; runs round box uttering slight cries. Twitches of head. Discharge of watery fæces.

10 0. Belly very unduly swollen on the side on which the injection was made, due probably to tympanitis.

10 10. Contrives to get into a corner and moans, twitching its head convulsively.

Discharge of urine. No observation was made prior to injection as to the state of the pupils; but from a comparison with other animals they would seem to be dilated: they are quite sensitive to light.

10 25. Hemiplegia of right side very marked.

10 30. Respirations 132 per minute (22 in 10 seconds). (The heart-beats were so feeble that they could not easily be counted.)

10 45. Cries when the abdomen is touched.

11 0. Urine and fæces discharged; utters low cries. Can move quite well and normally.

11 25. Evidently very uneasy; cries continually. Respirations 140 per minute (23·3 in 10 seconds).

12 0. Still sensitive.

12 15. Walks about normally.

12 35. Respirations 132 per minute (22 in 10 seconds).

h. m.

3 0. The animal has exhibited no fresh symptoms; it is, however, now breathing more rapidly (33·3 in 10 seconds), as if much exhausted. It is quite sensitive.

3 45. Breathes very heavily, with a gurgling noise in the throat.

3 50. No paralysis, but great weakness and evident pain.

4 5. Breathing 76 per minute (12·6 in 10 seconds) and irregular.

4 45. Creeps along, evidently very weak.

5 10. Still sensitive; on touching the eyeball the lid moved languidly.

5 30. Gurgling noise in throat; struggles as if in great pain; drops of serous fluid exude from the nose; asphyxia. Eyes prominent. Gasps at intervals of 5–6 seconds. Heart has ceased to beat. Serous exudation from nose and mouth.

5 35. Dead.

Post mortem Examination.

Muscles contract on direct stimulation.

Blood dark-coloured, asphyxial.

6 5. Heart contracts on stimulation; right side distended.

General visceral congestion.

Liver pale, but otherwise normal.

Lungs congested, mottled with purple, the upper lobes more than the lower, and the left lung more than the right.

Stomach congested internally, especially near the smaller curvature and vertebral aspect, becoming less so towards the cardiac end, where, however, there is one piece of arborescent congestion apparent. There is another such patch on the abdominal aspect (internal surface) of the same viscus.

Œsophagus hardly congested.

Duodenum congested in patches internally at the free border, especially towards the lower end.

Great congestion of the free border of the small intestine, becoming more extensive as we descend. Towards its lower end the small intestine is filled with a brown opaque mucus.

Large intestine not nearly so much congested as small. Rectum partakes of the characters of the rest of the large intestine.

Bladder contracted and not congested.

Uterus slightly congested externally, but not so internally.

Kidney congested internally.

From this experiment we learn that 25 milligrammes of V_2O_5 produced death in $8\frac{3}{4}$ hours, and that symptoms of poisoning began to appear within 20 minutes. The symptoms were convulsive twitchings, partial and temporary paralysis, abdominal pain, rapid respiration. No importance can be attached to the apparent dilatation of the pupils, as it may have been due to the shade of the box. After death there were very evident traces of great congestion of alimentary mucous membranes (especially at the free border of the small intestines) and of the lungs.

Exp. XVI.—February 18, 1874.

Weight 667 grms.

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes of V_2O_5), injected under the skin.

In this experiment 50 milligrammes of V_2O_5 produced death in 23 minutes from the time of injection. Symptoms began to appear within 10 minutes of injection. The symptoms were such as we have seen in preceding experiments, viz. indifference to surrounding circumstances, paralysis, especially of the hind limbs. The heart's vitality was not affected.

On Rabbits.

Exp. XVII.—January 23, 1874.

Weight 1373 grms.

Dose 4 cub. centims. of the 5 per cent. solution (200 milligrammes V_2O_5), injected under the skin of the right shoulder.

In this experiment 200 milligrammes of V_2O_5 produced death in a rabbit of 1373 grms. in 12 minutes. The poison produced death clearly by acting at once upon the nervous system, causing severe convulsions, and without inducing decided inflammation of the alimentary mucous membranes.

Exp. XVIII.—February 6, 1874.

Weight 1705 grms.

Dose ·5 cub. centim. of a 5 per cent. solution (25 milligrammes V_2O_5), injected under the skin.

From this experiment we learn that 25 milligrammes of V_2O_5 produced death in a rabbit of 1705 grms. in 49 minutes; that symptoms of poisoning set in within 30 minutes of injection. The symptoms agree with those of the previous experiment; and, coincident with the shallow and rapid respiration, there was a fall of 1°·5 C. in temperature. The temperature in the rectum remained constant for some time after death.

Exp. XIX.—February 11, 1874.

Weight 1449 grms.

Dose 1 cub. centim. of a ·25 per cent. solution prepared from the standard 5 per cent. solution (2·5 milligrammes V_2O_5), injected under the skin.

In this case a very small dose was injected; and no symptoms, distinctly attributable to poison, followed, except a slight indifference to external objects.

Exp. XX.—February 13, 1874.

Weight 1449 grms.

Dose 1 cub. centim. of a ·5 per cent. solution prepared as above (5 milligrammes V_2O_5), injected under the skin.

(This was the same rabbit as was used in the preceding experiment.)

In this experiment 5 milligrammes of V_2O_5 produced in a rabbit of 1449 grms. distinct symptoms of poisoning, but no fatal result. The symptoms were, as before, partial paralysis, paraplegia of the lower extremities, slight convulsions, excited respirations, drowsiness, and they appeared within 25 minutes of injection.

Exp. XXI.—February 18, 1874.

Weight 1392 grms.

Dose 5 cub. centims. of the 5 per cent. solution (250 milligrammes V_2O_5), injected under the skin of the belly.

Heart-beats in 10 seconds .	52	determined prior to injection.
,, ,, .	53	
Respirations in 10 seconds .	22	
,, ,, .	24	

h.	m.	s.	
12	37	0.	Injection complete.
12	39	30.	Weakness of posterior extremities.
12	40	0.	Almost complete paralysis of posterior extremity of body.
12	42	0.	General agitation, alternating with an appearance of somnolence.
12	44	0.	Breathing has almost ceased. Quivering over hind quarters. Heart exceedingly weak and slow.
12	46	30.	Twitching of head to one side. General convulsive movements of an opisthotonic character. Quivering, and dilatation of pupil.
12	47	0.	Cornea insensitive; pupil dilated. Jaws open once or twice in a gasping manner. Death.

Post mortem Examination.

Heart feebly pulsating; both ventricles moderately distended. Vena cava not much distended. Lungs somewhat pale. Lower part of small intestine normal. Duodenum and upper part of jejunum contained much glairy mucus, which in some places was frothing. Mucous membrane seems to be slightly swollen and congested.

In this experiment 250 milligrammes of V_2O_5 produced death in a rabbit of 1392 grms. in 10 minutes, the poison commencing to operate within $2\frac{1}{2}$ minutes of injection. The symptoms, as before, were paralysis of hinder extremities, convulsions, drowsiness, an affection of respiration and of the cardiac movements, and congestion of alimentary mucous membrane.

Exp. XXII.—March 5, 1874.

Weight 1386 grms.

Note.—The rabbit (doe) seems weak, and is suffering from some skin disease.

Dose 4 cub. centims. of 5 per cent. solution (200 milligrammes V_2O_5), injected under the skin.

Note.—The solution was afterwards discovered to be uncertain as to strength. The experiment is inserted for the general symptoms, which it exhibits very well.

Temperature in rectum . . 37°·4 C.
Respirations in 10 seconds . 15
" " . 16
Heart-beats in 10 seconds . 40
} determined prior to injection.

h. m. s.
1 6 0. Injection commenced.
1 8 0. Injection complete.
1 11 0. Runs about. Discharge of normal fæces. Respirations in 10 seconds, 20, and irregular.
1 14 0. Heart-beats in 10 seconds, 30.
1 16 0. Respirations in 10 seconds, 10.
1 17 30. Rests head against side of box.
1 18 30. Respirations in 10 seconds, 12·5.
1 19 30. Respirations in 10 seconds, 14·6.
1 21 0. Drowsy. Heart beats so feebly as to render counting impossible.
1 21 30. Respirations in 10 seconds, 19.
1 22 30. Respirations in 10 seconds, 17·3.
1 22 45. Drowsy; lies down on side.
1 23 30. Respirations in 10 seconds, 20. Evident uneasiness; sprawls out its hind legs. Closes eyes.
1 24 30. Respirations in 10 seconds, 8 (about). Paraplegia; rocking of head; bending back of head.
1 25 0. Attempts to lie on side; closes eyes, and lies with head low. Lies on its belly.
1 26 30. Respirations in 10 seconds, 12.
1 27 0. Opisthotonos; lies on side; pupil distended; cries.
1 28 0. Cornea but slightly sensitive.
1 28 15. Gasps; cornea insensitive to touch. Rabbit insensitive on pinching.
1 29 0. Dead.
1 29 30. Quivering of skin over hind legs.
1 32 0. Pupil contracted; curious shaking of fore and hind limbs.
1 33 0. Temperature in rectum 36°·6 C.

Post mortem Examination.

h. m.
1 37. Heart still beating (left auricle), 36 in 10 seconds.
Right heart distended; left heart contracted.
1 40. Right auricle beating; right ventricle beats on stimulation, but not so the left ventricle.
The pericardium contains a quantity of colourless effusion.
Temperature in rectum 36°·7 C.

From what was said at the beginning of this experiment the above results are valueless as regards the lethal dose. The symptoms of poisoning appeared in less than 15 minutes after injection, and were confirmatory of those stated in previous experiments. A rapid increase in the number of respirations per minute was one of the first signs of the action of the poison. When paraplegia became well marked the respirations sank suddenly from 20 in 10 seconds to 8 in 10 seconds and 12 in 10 seconds. The pulse sank and became very feeble, and the temperature sank (as in Exp. XVIII.) about ·8° C., and maintained that lower temperature for some time after death.

Exp. XXIII.—March 20, 1874.

Weight 2066 grms.

Dose 5 cub. centims. of a 5 per cent. solution (250 milligrammes V_2O_5), injected under the skin. (A small amount was lost in injecting.)

In this experiment 250 milligrammes of V_2O_5 produced death in a rabbit of 2066 grms. in from 8 to 9 minutes. Symptoms of poisoning commenced to appear within from 2 to 3 minutes of injection, and were exactly confirmatory of those in the preceding experiment, viz. a marked increase in the number of respirations (which supervened more rapidly than in the preceding experiment), followed, when the nervous symptoms became very decided, by a sudden fall, a feebleness of heart-beat, and paralytic and convulsive symptoms.

Exp. XXIV.—May 6, 1874.

Weight 1280 grms.

Dose 5 cub. centims. of a 5 per cent. solution (250 milligrammes V_2O_5), injected under the skin of the back.

In this experiment 250 milligrammes of V_2O_5 caused death in a rabbit of 1280 grms. in from 5 to 6 minutes. The symptoms developed within 2 minutes of injection, and exactly confirmed those of the preceding experiment.

Exp. XXV.—May 6, 1874.

Weight 1672 grms.

Dose 5 cub. centims. of a 5 per cent. solution (250 milligrammes V_2O_5), injected under the skin of the back.

In this experiment 250 milligrammes of V_2O_5 caused death in a rabbit of 1672 grms.

in 10 minutes. Symptoms developed within 2 minutes of injection, and confirmed those of the preceding experiment.

On Dogs.

Exp. XXVI.—December 10, 1874.

The dog was a small, rough, young terrier; it had been used five days before in an experiment in which 100 milligrammes (?) of V_2O_5 had been injected (in the form of neutral sodium vanadate) into the right external jugular vein without producing death. It had apparently completely recovered.

Dose 10 cub. centims. of the 5 per cent. solution (500 milligrammes V_2O_5), injected under the skin of the back.

h. m.
11 50. Injection complete; dog slightly sick.
12 5. Much terrified; slight diarrhœa; vomits a stringy mucus; walks quite well.
12 20. Vomited more mucus of a tenacious ropy nature.
12 50. Salivated. Discharge of watery matter from rectum.
1 15. Watery discharge *per rectum* continues, together with a quantity of light, loose fæces.
1 40. Breathing irregular.
2 0. Attempts to vomit ineffectually; breathing rather laboured and irregular; watery discharge from rectum continues.
2 40. Again sick; vomited more stringy mucus. Discharge from rectum still continues.
3 25. Symptoms as before; breathing irregular and laboured; watery discharge from rectum as before.
3 40. No paralysis or convulsions have as yet been noticed; breathing heavy.
4 30. Still salivated.
5 15. Appears unable longer to support itself, and has fallen over on to its side; breathing short and irregular; quite conscious.
5 25. Raised itself and sat up, but with great difficulty; sways about as if weak and unable to hold itself steadily upright.
5 30. Lies down again; quite conscious.
6 0. Region around the anus covered with a sanguineous watery matter which has issued from it during the afternoon.
6 30. Quite conscious.
7 0. Quite conscious.
7 10. Breathes heavily and at short intervals.
8 0. Conscious; breathing slight.
8 40. Eyeball but slightly sensitive.
9 40. Still breathing.
10 55. Dead.

Post mortem Examination.

Blood very dark in colour; exhibits the normal hæmoglobin bands; coagulates firmly and normally.

Muscles irritable to tactile stimuli.

Heart not irritable; right side distended.

Liver normal; or, if any thing, darker than usual.

Stomach empty of food, but filled with a tenacious mucus; general congestion of mucous membrane, especially over the posterior surface, except near the pylorus, where it has the normal tint. On examination of the more highly congested regions we can make out that the arborescent injection is especially to be observed on the summits of the prominent rugæ, and is irregularly scattered over the mucous membrane bordering the alveoli.

At some points extravasations of blood of a very limited extent are to be seen.

Duodenum is in a state of intense congestion, covered with dark red mucus in which are seen under the microscope innumerable blood-corpuscles and epithelial cells.

The same appearances exhibited by the rest of the small intestine; undoubted extravasations of blood exist besides the congestion. A PEYER's patch at the lower end of the ileum is undoubtedly enlarged; its borders are elevated, but, strangely enough, it is not so deeply injected as the adjacent mucous membrane.

Rectum undoubtedly injected.

Kidneys normal at the cortex, but slightly congested at the pyramids.

The blood yielded little or no serum after standing over night in the laboratory.

The intestine and liver, which were examined for vanadium in Dr. ROSCOE's laboratory, were found to contain it. The following is the report of Mr. S. CARSON, who made the determination for us:—

"The intestines were cut up into small pieces and roasted in a platinum dish in a muffle-furnace until all the organic matter was burnt away. The ash left was moistened with a little pure HCl and warmed for some time on the water-bath. Water was then added; and after boiling for some time, the insoluble portion was filtered off and the filtrate (which had a distinct blue colour) examined for vanadium. It was evaporated to dryness and fused with a little KNO_3; the mass was again taken up by water, and a little oxalic acid added, which brought out the blue colour more distinctly. It was sought to estimate the vanadium in this solution by precipitating with $(NH_4)Cl$, but the quantity present was too small to admit of quantitative estimation.

"The liver was examined in the same way, and the blue colour due to vanadium was obtained on adding oxalic acid; but the coloration was not so dark as in the case of the intestines."

In this experiment 500 milligrammes of V_2O_5 caused death in a young and small dog in 11 hours 5 minutes, poisonous symptoms developing about 15 minutes after injection. The prominent symptoms were the vomiting of a thick, ropy mucus, salivation, and the almost continual discharge of at first a watery and afterwards a sanguinolent fluid *per rectum.* Respiration was irregular, and afterwards laboured and heavy. No nervous symptoms, such as were so characteristic in the case of rabbits, guineapigs, and frogs, were observed; and the animal was evidently conscious to the last. A *post mortem* examination disclosed evidences of an intense congestion of alimentary mucous membranes accompanied by distinct extravasations of blood. The blood coagulated normally, but yielded very little serum. Muscles retained their irritability to mechanical stimuli. Vanadium was discovered to be present in the tissues (not free from blood) of the liver and intestines.

Exp. XXVII.—February 20, 1874.

The dog used was a young English (black and tanned) terrier.

Dose 20 cub. centims. of the 5 per cent. solution was evaporated down carefully to a bulk convenient for subcutaneous injection. The dose equalled 1 grm. V_2O_5.

In this experiment 1 grm. of V_2O_5 caused death in a young and small dog in 7 hours 55 minutes, symptoms developing within 20 minutes of injection. The symptoms in the main confirm those of the preceding experiment, except that salivation did not occur here.

On Cats.

Exp. XXVIII.—December 12, 1873.

The cat was small and adult.

Dose 5 cub. centims. of the 5 per cent. solution (250 milligrammes V_2O_5), injected under the skin of the back.

h. m.
2 20. Injection complete.
2 22. Vomits.
2 23. Discharge of fæces.
2 28. Again sick.
2 30. Great contractions of abdominal muscles and diarrhœa. Again sick.
2 35. Vomits a watery fluid.
2 37. Respirations about 15 in 10 seconds. Very much depressed; attempts to discharge fæces.
2 45. Respirations 16 in 10 seconds.
2 50. Salivation, the saliva being viscid. Respiration irregular, heavy, and chiefly abdominal.

h. m.

3 0. Very feeble; may be handled with impunity. Respirations rapid, and heart extremely feeble.

3 15. Rolls over two or three times, as if in pain; breathing very rapid and shallow. Rises, but cannot stand; lies on its side, stretches out its fore paws, and seizes with them the bars of its cage. Slight opisthotonos.

Right posterior extremity drawn forward. Great dyspnœa apparently. Moans.

3 20. On touching the cornea the eye was not closed. Dead.

Post mortem Examination.

Divested the animal of its skin.

Irritability of the pectoral muscles was noticed on touching them with the forceps. The heart was not contracting; the right side was distended with blood; on exciting the heart directly it contracted. The right ventricle was filled with a cherry-coloured blood, which took $3\frac{1}{2}$ minutes to coagulate.

3 47. The left side of the heart contains very little blood.

3 55. Œsophagus perfectly normal.

Trachea exhibits no marked congestion.

Lungs normal.

Abdominal viscera exhibit distinct general congestion.

Pancreas normal.

Stomach exhibits, on being opened, not the slightest congestion.

The whole of the small intestine is congested, the duodenum and jejunum being more distinctly so than the parts lower down. The congested intestines are covered with a viscid and transparent mucus. At points the intestinal mucous membrane appears to be the seat of ecchymosis. At the ileo-cæcal valve there is a patch of intense congestion and a small abrasion of mucous membrane, the abraded part being covered with mucus.

The cortical and pelvic parts of the kidney are quite normal; the pyramids, if any thing, are slightly congested.

Dr. Julius Dreschfeld confirmed the above observations.

The intestines of the cat were sent to Mr. S. Carson for examination. He reports:—"In the examination of the mucous membrane of the cat I did not succeed in finding any trace of vanadium."

In this experiment 250 milligrammes of V_2O_5 caused the death of a small adult cat in 1 hour, symptoms developing within 3 minutes of injection. The symptoms were partly confirmatory of those in the preceding experiments on dogs, viz. sickness, salivation, irregular respiration (which was noticeably rapid in this case), diarrhœa, great pain. In addition, nervous symptoms supervened analogous to those noticed in the case of rabbits, &c. The *post mortem* appearances resembled exactly those in the cases of the dogs, but, owing to the rapidity of death, they were not so extensive or marked. Chemical examination of the intestines failed to show the presence of vanadium.

Exp. XXIX.—February 18, 1874.

Weight 1310 grms. A small cat.
Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes $V_2 O_5$), injected under the skin.

In this experiment 50 milligrammes of $V_2 O_5$ caused the death of a small cat. As far as was observed, the symptoms were those of irritation of the alimentary mucous membranes, viz. vomiting, retching, and congestion of the interior of the stomach and intestines. The intestines, in their lower portion, contained much brown mucous fluid; and epithelium-cells, blood-, and mucus-corpuscles were found free in the stomach. The lungs were much congested and frothy.

ii. *Action of the Drug when introduced into the System by direct Injection into Blood-vessels.*

Only one experiment was performed with the express object of determining the effect of direct injection into the vascular system. In investigating the special action of vanadium upon circulation and respiration, however, frequent use was made of this mode of injection; and reference will be made, in the *Résumé* of the General Action of Vanadium (p. 518), to the experiments then performed.

Exp. XXX.—December 5, 1873.

The dog was a small rough terrier, rather young.
Dose 2 cub. centims. of a 5 per cent. solution (100 milligrammes $V_2 O_5$), injected into the right external jugular vein.
Note.—Some of the solution was lost during injection.

In this experiment (less than) 100 milligrammes of $V_2 O_5$ were insufficient to cause death in a small young dog when directly injected into a vein. The only symptom attributable to vanadium-poisoning was the drowsiness which followed on injection. On comparing this experiment with Experiment XXVI., in which 500 milligrammes of $V_2 O_5$ injected subcutaneously produced death in about 11 hours, it seems probable that a considerable quantity of the solution was lost in this experiment during injection.

For further observations of the action of vanadium on the system, when injected directly into blood-vessels, see Experiments XLII. to LX. (on Circulation and on Respiration).

iii. *Action of the Poison when introduced into the System by Injection into the Alimentary Canal.*

Exp. XXXI.—June 10, 1875.

Rabbit.—Weight 2430 grms.

Dose 5 cub. centims. of the 5 per cent. solution (250 milligrammes V_2O_5), injected by means of a catheter into the stomach.

h. m.

11 45. Injection complete. Very quiet.

12 10. Sudden convulsions (opisthotonos ?). Lies out on belly. Respiration rapid and shallow.

On touching the leg of the rabbit the latter got up and walked.

12 20. Temperature in rectum 38°·9 C. (The temperature prior to injection was 40°·2.)

12 30. Very quiet.

12 55. Lies out at length with legs spread out; gets up when its legs are touched.

1 10. Respiration not so rapid. Quiet.

1 50. Temperature in rectum 38° C.

Very slight watery rectal discharge. Very quiet. Respiration deeper and more regular (14 in 10 seconds).

3 0. Still lies with legs spread out behind; can move them quite normally, however. Respiration has normal characters (15 in 10 seconds). Temperature 38° C.

No further rectal discharge has taken place; the region around the anus, however, is moist.

4 0. Very quiet. Respiration as above (16 in 10 seconds). Rocks head as if weak. Sluggish movements of the eyelids on touching the cornea.

4 10. Discharge of urine. Rabbit leans against the side of the box, as if weak.

Respiration seems weaker.

4 15. Respiration 12·5 in 10 seconds.

4 25. Respiration 10–11 in 10 seconds.

Leans in a corner of the box, as if weak. Region about the anus moist with brownish fluid.

4 45. Temperature 38°·3 C.

5 30. Rabbit evidently very weak. No fresh symptoms. Respiration 11 in 10 seconds.

On being irritated it moves to another part of the box quite normally.

6 0. Symptoms as before.

7 45. Symptoms as before in general; rabbit weaker. Temperature 35° C.

9 0. Symptoms as before; region about anus moist with brownish or yellowish fluid.

h. m.

10 45. Symptoms as before in general; weaker. Respiration 12 in 10 seconds. Region about anus moist as before. Temperature 34° C.

12 35. As before. Moves spontaneously.

1 0. I had left the laboratory for half an hour. On returning at this hour I found the rabbit lying on the floor at some distance from its box, quite dead and stiff, with fore and hind legs spread out forwards and backwards respectively, as if it had had stretching-convulsions. The rabbit was certainly too weak to leap out of its box on to the table and thence to the floor; it must therefore have been projected from its box, which was narrow and 18 inches high, on to the floor during the death-struggles.

Post mortem Examination.

Heart is not acting: filled with venous blood. Stomach not very full; contents of the usual green colour. Mucous membrane intensely and extensively congested, except at the pyloric end. A few spots of extravasation.

Intestine everywhere more or less congested, filled with a greyish mucus; the vermiform appendage filled with much dark, fluid, and very fæcal matter. The mucous membrane of the intestine exhibits everywhere numerous, but not thickly set, large, thickened spots ($\frac{1}{8}$ inch in diameter and less), with a yellow centre and intensely red periphery, which do not seem to be confined to any border in particular.

Kidney seems normal.

Lungs not congested.

Liver firm, greyish internally, and, so far as can be made out, very slightly fatty.

From this experiment we gather that the effects of large doses of sodium vanadate *per œsophageum* resemble those of small doses when subcutaneously injected. Respiration becomes rapid and shallow at first, but quickly falls again to the normal. At the same time the temperature falls about 1° C., and never again attains its previous height. Convulsions occurred only once, at the beginning of the experiment. The stretching-out of the hind legs may have been due to imperfect paralysis, but at no time was paralysis complete. Death must have been accompanied by severe convulsive struggles, and was preceded by great weakness and depression of temperature. The great alimentary congestion and the presence in quantities of viscid intestinal contents indicate the chief action of the poison. Death occurred in 13 hours after injection.

Exp. XXXII.—June 10, 1875.

Rabbit.—Weight 2720 grms.

Dose 3 cub. centims. of the 5 per cent. solution (150 milligrammes V_2O_5), injected *per rectum.*

The rabbit had quite recovered by the next day.

In this experiment the only symptom of poisoning was a rapidity of respiration, unaccompanied by any fall in temperature attributable to vanadium.

Exp. XXXIII.—September 15, 1874.

Rabbit.—Weight 1670 grms.

Dose 3 cub. centims. of the 5 per cent. solution (150 milligrammes V_2O_5), injected into the stomach.

In this experiment the dose of 3 cub. centims. was simply injected into the stomach instead of into the rectum. There was no marked respiratory symptom, the rabbit appearing throughout to be quite normal. The rabbit recovered.

No effect was produced by the injection of 150 milligrammes V_2O_5 into the stomach.

Exp. XXXIV.—September 16, 1874.

Guineapig.—Weight 630 grms.

Dose 5 cub. centims. of the 5 per cent. solution (250 milligrammes V_2O_5), injected into the stomach.

h. m. s.
11 38 0. Injection complete.
11 40 0. Movements as of vomiting. Retching: seems quiet and ill. Moves spontaneously.
11 41 30. Retching; defecates; retches; vomits a dark green tenacious fluid, which oozes from nostrils as well as mouth.
11 47 0. Moves about unsteadily; jerks forward at each respiration, as if weak; moves unsteadily; lies down, as if weak.
11 50 0. Unsteady. On moving the head shakes, as if the animal were very weak or "nervous." Moves about.
11 52 0. Gasps; vomits again; very weak apparently. Crawls along very unsteadily.
11 54 0. Gasps; vomits.
11 55 0. Gasps; moves about uneasily; jerks its head; crawls along uneasily; jerks its head, as if hiccoughing.
11 59 0. Twitches head and hind limbs.
12 0 0. Spasmodic jerks of head and body.
12 2 0. Turns over on to its side; deep gasps; eye but slightly sensitive.
12 4 0. Gasps at long intervals. Hind legs quite flaccid and apparently insensible; gasps shallower; eye insensitive.
12 5 0. Dead.

Post mortem Examination.

Muscles irritable on striking.

Lungs congested at the back.

Liver appears normal.

Congestion of abdominal viscera.

Normal peristaltic action of the intestines.

Stomach filled with bright green contents. Walls much congested, especially near the cardiac end and lesser curvature.

Duodenum filled with bright green contents. The mucous membrane is covered with a thick yellowish tenacious matter, which hides a deep congestion beneath.

Jejunum contains a darker green substance, and is also much congested in its mucous membrane.

Ileum presents the same appearance as the jejunum.

Rectum not congested.

Kidney not congested.

Œsophagus not congested.

In this experiment 250 milligrammes of V_2O_5 caused death in a guineapig within 27 minutes. Death was preceded by the vomiting of a greenish fluid, an unsteadiness of gait and great apparent weakness, a gasping respiration, and convulsive twitches of head and hind limbs. A *post mortem* examination disclosed a congestion of the lungs (Is this due to the action of vanadate of sodium?) and intestinal mucous membranes, as well as the presence in the alimentary canal of green contents.

Exp. XXXV.—September 17, 1874.

Guineapig.—Weight 505 grms.

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes V_2O_5), injected into the stomach.

In this experiment the animal died in less than a day after injection. The symptoms were trembling and an excessive discharge of urine. The urine was tested by shaking it up with ether containing hydrogen peroxide, which causes with vanadic acid a red coloration; it contained no vanadic acid in such amount as to be capable of detection. The *post mortem* appearances indicated gastric congestion.

Exp. XXXVI.—September 18, 1874.

Guineapig.—Weight 463 grms.

Dose 2 cub. centims. of the 5 per cent. solution (100 milligrammes V_2O_5), injected into the stomach.

Sept. 19.—The guineapig had died in the night.

In this experiment the guineapig died in less than a day after injection. The only symptom noticed during the five hours of observation immediately after injection was an excessive secretion of urine.

Lethal Dose.

From the preceding experiments on rabbits the minimum lethal dose of vanadic pentoxide in the form of sodium vanadate was determined for those animals.

In Exp. XX. a rabbit weighing 1449 grammes had sodium vanadate subcutaneously injected containing 5 milligrammes V_2O_5. The rabbit recovered; that is to say, 3·45 milligrammes V_2O_5 per kilogramme of rabbit are insufficient to cause death.

In Exp. XVIII. a rabbit weighing 1705 grammes was injected subcutaneously with a similar solution containing 25 milligrammes V_2O_5. The rabbit died; therefore 14·66 milligrammes V_2O_5 per kilogramme of rabbit are sufficient to cause death.

A rabbit was taken weighing 2720 grammes (it was the same rabbit as had recovered four days previously from the injection *per rectum* of 150 milligrammes V_2O_5; see Exp. XXXII.). A solution of sodium vanadate was prepared containing 25 milligrammes V_2O_5, *i. e.* 9·18 milligrammes per kilogramme of rabbit, and injected subcutaneously. Marked symptoms of poisoning occurred—rapid respiration, sluggishness, rocking of head, partial paralysis and weakness, which lasted for about an hour and a half; after which the rabbit became rapidly normal, and completely recovered.

It was deemed unnecessary, in the case of a body like vanadium, to sacrifice more rabbits in order to fix with greater exactness the lethal dose. The minimum lethal dose, therefore, lies between 14·66 milligrammes and 9·18 milligrammes of V_2O_5 per kilogramme of rabbit.

Résumé of the General Action of Vanadium.

A review of the experiments on the general action of sodium vanadate on the animal economy displays two well-marked modes of action, by either of which, or by both combined, the poison may produce death. The first, an action on the nervous system, takes in frogs the form of gradual paralysis, first of respiration, and afterwards of motion generally; and in pigeons, guineapigs, rabbits, and cats, of drowsiness, or indifference to external circumstances, together with partial paralysis and convulsions affecting some or all of the muscles of the body. The second, an action on the alimentary mucous membrane, exists in frogs only in cases of slow poisoning, and is evidenced by congestion of the interior of the alimentary canal. In pigeons, in which, when the dose of the salt has been small, it precedes the nervous symptoms by some hours, it is evidenced by the discharge of sanguinolent fluid fæces during life, and after death by the congested condition of the alimentary mucous membrane and the quantity of mucous contents of the intestine. In guineapigs, in which, on the contrary, the nervous symptoms are more important, congestion of the alimentary tract (which is especially noticeable when the dose of poison has been small) sufficiently attests the presence of intestinal mischief. In rabbits, again, the nervous affection is more prominent, and in the majority of cases is clearly the proximate cause of death. But in their case, as in that of guineapigs, signs of congestion in the intestines, and the presence in them of quantities of glairy fluid after poisoning, prove the existence of irritation. In the case of dogs the doses administered, although relatively large, failed to produce any nervous symptoms whatever; and the intense gastric and intestinal congestion and blood-extravasations, together with the evident signs of great abdominal pain, vomiting, and watery or sanguinolent rectal discharges, during life, gave unmistakable indication of the cause of death. In cats, which are killed by much smaller doses of V_2O_5 than dogs, nervous symptoms (convulsions) occurred, in addition to the signs of intestinal irritation, which were similar, though, owing to the rapidity of death, not so marked as in dogs.

Besides those above mentioned, indications of disorder in other portions of the animal system were noticeable. Thus, in guineapigs and rabbits, one of the earliest symptoms of poisoning was that respiration became rapid and shallow; and when steps were taken for exact observations, it was found in rabbits (1) that this alteration in the character of the respirations was accompanied by a fall of about 1° C. in temperature, and (2) that as soon as the nervous symptoms became well marked the number of respirations per minute sank at once.

Drowsiness or indifference to external circumstances was noticed in all cases of vanadium-poisoning, and it often supervened extremely rapidly after introduction of the drug. Consciousness did not seem in any case to be impaired, as far as it was possible to judge. Sensibility to pain also seemed perfect. The cord and brain were not congested.

Congestion of the lungs was observed to follow in some guineapigs and one cat, but not in rabbits or dogs.

Muscular and nervous irritability remained for many hours in all cases where indications of it were sought, and appeared normal.

In rabbits the pulse was noticed to be slow and feeble. The hearts of frogs continued to beat for a long time after paralysis of motion was complete, and the hearts of rabbits &c. were always irritable, if not contracting, for some time after death.

When injected into the stomach the general symptoms were similar in kind to those mentioned above; in addition, great prostration followed in rabbits, and, in guineapigs, vomiting when the dose was large, and excessive secretion of urine when it was small.

The minimum lethal dose for rabbits, when injected under the skin, lies between 14·66 and 9·18 milligrammes of V_2O_5 per kilogramme.

B. SPECIAL ACTION ON VARIOUS FUNCTIONS OF THE ANIMAL BODY.

i. *Special Action of the Poison on the function of Muscular Tissue (after local application).*

On Voluntary Muscle.

Exp. XXXVII.—June 4, 1874.

1 h. 35 m. Decapitated a small toad. Cut off the legs at the knee, leaving the feet

attached. Laid bare the muscles down to where the feet commence. Irritated the muscles of both by means of an interrupted current (the secondary coil being at a distance of 20 centims. from the primary) and produced distinct movements in both. Placed one in a capsule filled with a ·5 per cent. solution NaCl, and the other in a 2 per cent. solution of V_2O_5 in the form of sodium vanadate. The leg in the vanadium solution appeared to stiffen a little.

Each leg was tested at intervals during the succeeding hours, by stimulating with induced (interrupted) currents, with the following results:—

Time.	Leg in Vanadium solution.	Leg in NaCl solution.
h. m.		
1 45	Moves with secondary coil at 16–17.	Moves with secondary coil at 20–21.
2 0	,, ,, 13.	,, ,, 20.
2 25	,, ,, 12.	,, ,, 20.
3 30	,, ,, 6–5.	,, ,, 20–23.
4 5	Slight movements with secondary coil at 0.	,, ,, 20–21.
4 50	No movements at all; leg stiffening.	,, ,, 20.
6 50	Leg stiff as if from rigor mortis.	,, ,, 20–23.
8 0	....	Movements not so brisk. Leg quite flexible; distinct movements with secondary coil at 8.

Exp. XXXVIII.—June 1875.

The gastrocnemii of two frogs were prepared in the same manner as in the preceding experiment. They were all tested, and the minimum stimulus in the case of each was found to be when the secondary coil was at 18.

The gastrocnemii of frog (α) were placed, one in a ·5 per cent. solution NaCl, and the other in a 1 per cent. solution V_2O_5 (sodium vanadate); those of frog (β) were placed, one in a ·5 per cent. solution and the other in a ·05 per cent. solution of V_2O_5 (sodium vanadate). On immersion into each of these liquids, muscular twitches were observed to follow in the legs, and in the legs in the 1 per cent. and ·5 per cent. solutions there were tetanic extensions. These muscular movements ceased in all cases after 20 minutes.

The muscles were tested by electrical stimuli at intervals, and within 2 hours 10 minutes all the muscles which had been immersed in solutions of the vanadium salt died, viz. that placed in the 1 per cent. solution within 1 hour 20 minutes, that placed in the ·5 per cent. solution within 2 hours 10 minutes, and that placed in the ·05 per cent. solution within 1 hour 38 minutes, the muscle placed in salt solution remaining sensibly normal.

From the preceding experiments we learn that solutions of vanadate of soda, even when very dilute, rapidly cause death when directly applied to muscle.

On Involuntary Muscle.

Exp. XXXIX.—June 1875.

Three frogs were taken and decapitated. The hearts of all were exposed, and the number of beats in 10 seconds counted. One heart was cut out of the body (including the sinus venosus) and placed in a ·5 per cent. solution of NaCl; another was prepared in the same manner, and placed in a solution of sodium vanadate of strength equivalent to a ·5 per cent. solution of V_2O_5. The third was not cut out of the body, but immersed together with the whole upper half of the body in a solution of strength equivalent to ·05 per cent. solution of V_2O_5, the pericardium having been previously cut away. The heart immersed in ·5 per cent. solution of the salt of vanadium ceased to beat and failed to contract on application of a powerful stimulus (electrical) within 25 minutes of immersion; that placed in ·05 per cent. solution within 40 minutes; while the heart which was placed in salt solution ceased to beat after 1 hour 45 minutes, and failed to respond to stimulation after 2 hours 12 minutes.

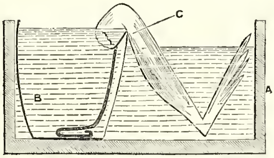
The results of this experiment are similar to those on voluntary muscle; extremely dilute solutions of sodium vanadate quickly cause death of muscular tissue when directly applied.

ii. *Special Action of the Poison on the function of Nervous Tissue (after local application).*

Exp. XL.—June 1874.

The legs of a frog were taken, and the sciatic nerve of each divided as high up as possible in the abdomen. The thigh was cut away above the knee, leaving the knee-joint intact. The nerves were tested, as a preliminary, by means of an interrupted current. Each leg moved when the secondary coil was 30 centims. from the primary. The arrangement drawn in the following diagram had been previously prepared for the reception of each leg:—

Fig. 1.



A is a glass capsule containing a ·5 per cent. solution of NaCl.
B is a crucible containing, in the case of one leg, a ·5 per cent. solution of NaCl, and in the case of the other a 2 per cent. solution of V_2O_5 in the form of sodium vanadate.
C shows the arrangement of the frog's limb and the nerve, the purpose of which is evident.

Helmholtz's arrangement of the induction-coil (interrupted currents) was used in stimulating the nerves from time to time, the minimum stimulus needed to produce contraction of muscles being in each case registered.

As before, the numbers represent the distance in centimetres between the two coils.

Time.	Leg whose nerve was immersed in NaCl solution.	Leg whose nerve was immersed in V_2O_5 solution.
h. m.		
4 30	Nerve immersed.	Nerve immersed.
4 50	Moves when the distance is 28–30.	Moves when the distance is 27.
5 0	,, ,, 27.	,, ,, 27.
5 15	,, ,, 25.	,, ,, 25.
5 30	,, ,, 24.	,, ,, 17.
5 45	,, ,, 23.	Twitches with distance 16.
6 7	,, ,, 21.	,, ,, 11.
6 40	,, ,, 21–22.	,, ,, 6.
8 0	,, ,, 19–20.	No movement at all with the secondary coil at 0.

Exp. XLI.—June 1875.

The above experiment was repeated exactly, except that the strength of the vanadium solution was equal to ·05 per cent. V_2O_5. At intervals during the experiment the muscles of both legs were tested by direct stimulation, and found to be normal as to their irritability throughout.

HELMHOLTZ's arrangement was not used. With the preliminary stimulation, while still in the body, both legs moved when stimulated with the secondary coil at 31–32 centims. Within 2 hours 40 minutes the nerve immersed in the ·05 per cent. solution of vanadium salt ceased to induce contraction in the attached muscles on application of electrical stimuli; while, on the other hand, the nerve immersed in the salt solution remained sensibly normal for more than 10 hours 45 minutes, when observations were discontinued.

The direct application of very dilute solutions of sodium vanadate rapidly causes death in nervous tissue.

Résumé of the action of Vanadium upon Muscle and Nerve on direct application.

Direct application of vanadium solutions to muscular and nervous tissues is rapidly fatal to them.

iii. *Special Action of the Poison on the Function of Circulation.*

The following experiments were undertaken with a view to detect the causes of the disturbance of circulation, by determining the special parts of the circulatory system affected by vanadium. In the experiments the blood-pressure was recorded by means of a mercurial kymographion, continuous tracings being often taken during the whole time occupied by the experiment. The rate of rotation of the cylinder was checked by means of an electro-magnetic marker, the circuit being made and broken by LUDWIG's Stromunterbrecher.

Both injection under the skin and injection into veins were made use of.

Exp. XLII.—March 4, 1874.

Rabbit.—Weight 1343 grms.

Dose 5 cub. centims. of the 5 per cent. solution (250 milligrammes V_2O_5), injected under the skin. The kymographic cannula was inserted into a carotid artery.

The rabbit died in 19 minutes 35 seconds after injection, and exhibited the usual general symptoms (see Experiments on pp. 505–508).

Note.—The solution was afterwards discovered to be under strength; hence the relatively long time the rabbit took to die.

Owing to the slight excursions of the pen at each heart-beat, it was impossible to obtain from the tracing of the experiment a series of numbers indicating rapidity of pulse.

From the record of the experiment we learn that, after the momentary rise due to the insertion of the injecting-syringe and the commencement of injection, the blood-pressure exhibited a succession of alternate rises and falls, gradually, however, attaining a lower and lower level until the death of the rabbit 19 minutes 35 seconds after injection. This alteration in the blood-pressure, as is shown by the tracing taken at the time, took place very regularly, and was only occasionally accompanied by struggles.

Exp. XLIII.—March 30, 1874.

Rabbit.—Weight 1834 grms.

Dose 5 cub. centims. of the 5 per cent. solution (250 milligrammes V_2O_5), injected under the skin.

The method of experiment resembled that of the foregoing. The rabbit died 10 minutes 30 seconds after injection. In this experiment, also, it was impossible to count the pulse from the kymographic tracing.

We learn that vanadium-poisoning causes the blood-pressure to fall from the moment of injection until death, that there are occasions on which the blood-pressure reasserts itself for a time, by a gradual rise, followed immediately by a gradual fall, and that once or twice the blood-pressure rose and fell in a jerky manner to a height of 15 or 20 millims. (having previously stood at about 45 millims.).

In the following experiment the attempt was made to prolong life by artificial respiration.

Exp. XLIV.—March 31, 1874.

Rabbit.—Weight 2075 grms.

Dose 5 cub. centims. of the 5 per cent. solution (250 milligrammes V_2O_5), injected under the skin.

The kymograph was connected with the right carotid artery.

The rabbit died within 22 minutes from the time of injection, artificial respiration being of no avail to prolong life.

From this experiment we learn that the blood-pressure declined steadily until the death of the rabbit, with the exception that once or twice it tended to regain its former level, the rise being accompanied sometimes by violent movements of the muscles.

On one occasion the rise and the muscular movements were both violent and sudden and simultaneous; but previously the convulsions or muscular movements preceded by about 15 seconds the rise, which was slow and accompanied by as gradual a fall. Although the record of the pulse is not very exact, as the rate of rotation of the cylinder was not checked, we can make out a decline in the number of heart-beats per 10 seconds, which is almost constant. The pulse, moreover, became at first much more marked as well as slower.

Exp. XLV.—May 13, 1874.

Rabbit (male).—Weight 1958 grms.

Dose 5 cub. centims. of the 5 per cent. solution (250 milligrammes V_2O_5), injected under the skin.

Time.	Mean B. P.	Pulse in 10 seconds.	Remarks.
h. m. s.			Kymographic cannula in left carotid artery; tracheal cannula fixed for simultaneous respiration-tracing (see p. 537).
1 41 0	128	38	Normals prior to injection; respiration-curves are shown; Excursion of pen at each pulse = 2 millims.
1 47 0	113	41	Injection finished; excursion of pen much less (= 1 millim.) at each pulse and irregular.
1 49 0	116	39	Irregular pulse; composed of alternate long and short beats.
1 49 30	98	30–33	
1 50 0	...	29–30	Pulsations irregular; irregularities in line of blood-pressure due to struggles; respiration-curves have disappeared.
1 52 30	96·5	36–38	Pulsations regular but slight.
1 53 45	84	23	
1 54 30	90	33–34	Pulse irregular and feeble.
1 54 45	94		
1 55 0	90		
1 56 30	83	27–28	
1 58 0	...	30	Pulse alternately long and short.
1 58 30	77	20	Pulse marked; excursion of pen = 2–3 millims.
2 0 0	74	28	Pulse regular but feeble.
2 1 30	62	19–20	Pulse deeper but regular.
2 2 30	67	22	
2 3 30	50	15	
2 6 0	36·5	22–16	
2 8 30	32	17	Pulse feeble but regular.
2 9 30	36·5	15	
2 10 30	38	13	Pulse feeble but regular. At this point a clot formed in the cannula and was removed.
2 12 45	62	18	The line indicating mean blood-pressure now commenced to describe long, sweeping curves; pulse deep and regular.
2 12 50	66		
2 13 0	52		
2 13 10	62	20	Pulse deep and regular; sweeping curves of B. P. line.
2 13 20	48		
2 13 30	53		
2 14 0	30	10	Pulsations deep, irregular and jerky.

Table (*continued*).

Time. h. m. s.	Mean B. P.	Pulse in 10 seconds.	Remarks.
2 14 30	42	20	Pulse regular and feeble; sweeping curves of B. P. line.
2 14 50	34	28	Sweeping curves of B. P. line.
2 15 30	71	29	Pulse regular and deeper; sweeping curves of B. P. line.
2 16 20	42	18–19	Pulse regular; sweeping curves of B. P. line.
2 16 30	50	23	Sweeping curves of B. P. line.
2 17 0	38	18	
2 18 0	42	33	
2 18 30	57	29	
2 19 0	32	19–23	Pulse irregular; struggles. Sweeping curves of B. P. line.
2 20 0	36	33	Pulse regular. Sweeping curves of B. P. line.
2 20 30	56	31	Sweeping curves of B. P. line.
2 21 10	29	23	
2 22 0	7	...	Pulse cannot be counted; gasps: dead.

This experiment, which was a very successful one, and deserves much weight, confirms the results of the preceding. From it we learn that under the action of vanadium-poisoning the blood-pressure commences to sink, and never again regains its former height; that this decline is at first pretty regular and constant; that, after a time, a series of rises and falls succeeds, during which the blood-pressure gradually traces on the rotating cylinder long, sweeping curves, which are not only not due to, but are altogether unaccompanied by, struggles or convulsions, thus showing that the muscular movements, which in preceding experiments coincided with similar rises and falls, were not, in all probability, the cause of them. In this experiment the rate of rotation of the cylinder was checked by the electro-magnetic marker, in consequence of which a full and accurate list of numbers denoting the rapidity of heart-beats was obtained. From this we gather that there is a decline in the rapidity of the heart as well as of the pressure of the blood, which commences almost as soon as injection is complete. This decline is also marked by periods during which the heart tends to its original rapidity of motion, without, however, at any time reaching it. It may be noticed that the variations in blood-pressure and in pulse are not always coincident.

In the following experiments injection took place into veins.

Exp. XLVI.—June 8, 1874.

Rabbit.—Weight 2180 grms.

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes V_2O_5), injected into the right external jugular vein.

Time. h. m. s.	Mean B. P.	Pulse in 10 seconds.	Remarks.
2 25 0	...	...	Kymographic cannula inserted into left femoral artery; cannula inserted into vein for injection.
2 25 0	100	35–40	Normals prior to injection. The respiration-curves are well shown.
2 30 0	97	35	Commence to inject. Respiration-curves well shown.
2 30 15	97	35	A sudden rise of B. P. to the extent of 10 millims. here took place without any alteration of pulse or respiration-curves.
2 30 20	106		
2 30 38	70	33	The B. P. now sank below the normal, and respiration-curves disappeared.
2 30 55	72	29	
2 31 0	...	11	Injection complete. The character of the pulse changed completely, becoming deeper, less regular, and less frequent. B. P. falling regularly.
2 31 45	35	11	The pulse is very irregular, shallow, and long.
2 32 40	24	12	The pulse is so undecided and irregular as to render counting difficult.
2 33 0	...	...	A sudden and irregular rise in B. P. from 22 millims. to 30 millims., followed by a less sudden fall to 22 millims., occurred at this point.
2 33 15	24	15	Pulse alternately long and short. Respiration 7–10 in 10 seconds and deep.
2 34 15	18	13–14	Respiration slight; eye insensitive; heart-beats long, regular, and dicrotic.
2 35 15	12	14	Pulse long and very irregular. Rabbit has been struggling. Respiration seems to have ceased.
2 36 30	10·5	14	Respiration resumed in a series of gasps.
2 38 30	8	...	Heart has ceased to beat; death.

In this experiment, in which vanadium was injected directly into a vein, the general symptoms are like those after injection under the skin, except that they supervene much more rapidly. Within 20 seconds after injection was commenced the blood-pressure rose rapidly from 97 to 106 millims., respiration-curves remaining normal. Within 38 seconds of the commencement of injection the blood-pressure had fallen below the normal, and respiration-curves were no longer to be seen, although the pulse was normal, except that it was slightly slower. From the time that injection was complete (1 minute after its commencement) the blood-pressure sank rapidly and almost constantly until the rabbit died, 7½ minutes afterwards. During injection the pulse appeared normal but somewhat slower; but immediately after injection its characters changed very suddenly indeed, its rapidity sank from 29 to 11 in 10 seconds, and it became at first deep and regular, and afterwards slight and irregular. About 5 minutes before death it picked up slightly. During the experiment the rabbit exhibited some struggles of a convulsive character, which were not, however, accompanied by any marked disturbance of blood-pressure.

Exp. XLVII.—June 15, 1874.

Rabbit.—Weight 2430 grms.

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes V_2O_5), injected into the right external jugular vein.

Time.	Mean B. P.	Pulse in 10 seconds.	Remarks.
h. m. s.			Kymographic cannula inserted into left carotid artery. Cannula in vein for injection. Cannula in trachea for simultaneous respiration tracing (see p. 538).
12 10 5	116	49	Normals prior to injection.
12 11 30	117	45	Normals prior to injection. Respiration-curves well shown.
12 14 55	117	49	Commenced to inject. About 10 seconds after the B. P. commenced to rise.
12 15 10	128	47	Injection complete. Pulse changed suddenly.
12 15 15	..	22	The B. P. sank more quickly than it rose; it sank to 70 millims., and afterwards began to rise again, reaching a height of 95 millims., owing to the rabbit's struggles. Respiration-curves disappeared.
12 15 20	70	..	
12 15 25	95	14	
12 15 40	48	12	Pulse regular and deep.
12 16 15	36	12	
12 16 45	31	14	Pulse shallower.
12 16 55	..	..	The B. P. rose several times very suddenly, owing to the struggles of the rabbit. Twice it attained a height of 61 millims.
	61		
12 17 40	31		
12 18 20	..	10–14	The rabbit began again to struggle; it appeared to be convulsed, exhibiting tonic spasms of the lower limbs. The eye became insensitive and the pupil dilated. The B. P. rose and fell irregularly.
12 18 45	22	5–6	The B. P. became steady and the pulse regular, long, and shallow.
12 20 20	..	10	Respiration in gasps; pulse very feeble.
12 21 30	14	..	Heart ceased to beat.
12 22 0	9	..	Dead.

In this experiment, with the exception of certain disturbances occasioned by the struggles of the animal, the variations in the character of the blood-pressure and the pulse resemble exactly those in the preceding one.

In the next two experiments it was desired to see the effects of poisoning by vanadium after section of both nervi vagi.

Exp. XLVIII.—February 19, 1874.

Rabbit.—Weight 1761 grms.

Dose 5 cub. centims. of the 5 per cent. solution (250 milligrammes V_2O_5), injected under the skin.

Time.	Mean B. P.	Pulse in 10 seconds.	Remarks.
h. m. s.			
4 21 0	112	50–57	Normals after insertion of cannula into left carotid artery for kymographic tracing and exposure of both nervi vagi. Respiration-curves are well shown ; pulse small.
4 22 0	106	. .	Both vagi divided ; respiration-curves shown ; pulse small.
4 22 15	136		
4 22 30	120	52	
4 23 0	. .	50–60	
4 28 38	112	60	Injection commenced.
4 29 0	116	62	Injection complete. Respiration-curves shown.
4 30 30	102	30	No respiration-curves ; pulse small ; long sweeping curves described by the kymographic pen.
4 30 40	120	28	Pulse dicrotic ; long sweeping curves of blood-pressure line as above.
4 30 55	93		
4 31 0	116	50	Respiration-curves pretty well shown ; long sweeping curves of line of blood-pressure.
4 31 15	86		
4 31 30	105		
4 31 40	82		
4 33 0	72	26	No respiration-curves.
4 34 10	50	30	
4 35 0	56	32	Respiration-curves shown.
4 36 0	48	31	Long sweeping curves, as above.
4 36 20	40		
4 36 25	50	. .	Struggles of rabbit, and irregular rises and falls of blood-pressure.
4 37 0	62	32	Pulse regular.
4 37 25	42	32	Pulse very faint. At this point there occurred numerous irregular rises and falls of blood-pressure coincident with respiration. Pulse cannot be counted.
4 38 0	62	32	Pulse regular.
4 38 20	38	. .	Pulse slight but regular.
4 44 0	28	. .	A delay had been occasioned by winding up the clockwork of the revolving cylinder, which had run out. Convulsions.
4 44 15	23	. .	Opisthotonic convulsions ; pulse cannot be counted ; blood-pressure very irregular, exhibiting sudden rises and falls.
4 45 0	0	. .	Dead.

The symptoms exhibited by this rabbit resemble in general those of the rabbit in Experiment XLV., where the same dose was injected in a similar manner without previous section of the vagi. Here, as there, the blood-pressure commenced to sink after poisoning; but at intervals it tended to regain its former height (even exceeding it at one moment) by gradual rises succeeded by gradual falls, the results of which are recorded on the recording cylinder as long, sweeping curves. The oscillations of blood-pressure, normally coincident with respiration, disappeared and reappeared several times in this experiment—a circumstance which was not noticed in Experiment XLV. In addition to these regular variations of blood-pressure, there occurred several jerky irregularities, due, apparently, in most cases, to struggles or convulsions. With respect to the pulse the comparison of the two experiments holds good also, when we take into consideration that the rapidity is, *in general*, greater in the case of the rabbit with divided vagi. Section of the vagi in rabbits does not at once cause the pulse to increase in rapidity. Bearing in mind, therefore, the fact that the full effect of division would occur *after* the injection of vanadium, we can see that there was a gradual decline of rapidity, marked, as we have noticed in preceding cases, by short periods of acceleration. For the rest, the animal exhibited the usual convulsions prior to death.

Exp. XLIX.—June 24, 1875.

Rabbit.—Weight 1315 grms.

Dose ·75 cub. centim. of the 5 per cent. solution (37·5 milligrammes V_2O_5), injected into the right external jugular vein.

Time.	Mean B. P.	Pulse in 10 seconds.	Remarks.
h. m. s.			Both vagi exposed; kymographic cannula inserted into the left carotid artery; cannula inserted into the right external jugular vein for injection.
4 45 0	101	..	Normal blood-pressure.
4 47 10	101	42	Normals prior to injection. Respiration-curves pretty well shown.
4 47 20	..	43	Left vagus divided. Blood-pressure rises. Respiration-curves well shown.
4 47 35	108		
4 47 40	..	48	Right vagus divided; blood-pressure rises.
4 48 0	142	41	Rabbit struggles and cries; irregularities of blood-pressure follow. Noise in throat of rabbit, due to paralysis of laryngeal muscles. Respirations 4 in 10 seconds.
4 49 10	118 108	48	
4 50 5	105	53	Injection commenced. Within 7 seconds of commencement the blood-pressure began to rise, reaching a maximum of 113 millims.
4 50 10	..	49	
4 50 15	113	46	
4 50 20	..	..	Injection complete. The blood-pressure fell suddenly, but rose again to 82 millims. The pulse changed suddenly in character, becoming at first shallow and rapid, then deep and irregular; the respiration-curves disappeared.
4 50 30	70 82	24	
4 51 0	..	27	Pulse rather more regular.
4 51 15	56	23	Respiration-curves have reappeared, and seem normal. Pulse seems composed of alternately short and long beats.
4 51 20	..	..	The rabbit here commenced to struggle, and continued to do so for two minutes, causing great disturbance in the blood-pressure and obscuring the pulse; respiration-curves have disappeared again.
4 53 10	24	10–11	Pulse very irregular. Further struggles, forcing the blood-pressure up.
4 54 30	18	11–12	Pulse more regular. Eye insensitive.
4 55 40	12	10	Respirations seem to have ceased.
4 59 0	6	3–4	Pulse remarkably shallow and long.
4 59 40	5	4	Death.

A comparison of this experiment with one (say Exp. XLVI.) in which the conditions were similar, except that the vagi remained intact (and the dose was slightly larger on account of the size of the rabbit), will show an almost exact similarity of symptoms. The slight divergence is, simply, that the general rapidity of pulse after injection in the experiment where the vagi were divided was greater than in the other—a circumstance which is explained by a consideration of the inhibitory functions of the vagus.

In the next three experiments the object was to discover the effects of poisoning by vanadium upon animals whose cords had been divided.

Exp. L.—June 23, 1874.

Rabbit.—Weight 2370 grms.

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes V_2O_5), injected into the left external jugular vein.

Time.	Mean B. P.	Pulse in 10 seconds.	Remarks.
			Tracheotomy: inserted metal tracheal tube; chloroform administered; cord exposed high in the neck; cannula inserted into vein for injection; kymographic cannula inserted into the left femoral artery.
h. m. s.			
5 2 0	..	..	·75 cub. centim. of 1 per cent. solution of curare injected into the vein; artificial respiration set up.
5 9 0	76		
5 12 0	74	54	Heart-beats are shallow and rapid.
5 12 45	108	51	On raising the rabbit's head with the purpose of dividing the cord, the blood-pressure went up suddenly, but fell again immediately.
5 12 50	78		
5 12 55	..	..	Commenced to divide the cord.
5 13 0	128	30	On inserting the knife the blood-pressure rose at once.
5 13 5	..	..	Division of cord complete.
5 13 30	..	46	After another slight rise the blood-pressure continued to descend until it stood steadily at about 22 millims. The pulse, which had become imperceptible soon after section, now became more vigorous.
5 14 30	24		
5 16 10	22	34	
5 16 40	22	37	Injection of vanadate commenced.
5 16 55	22	26	Injection complete; the pulse suddenly became less rapid and longer.
5 17 10	28	24	The blood-pressure rose with a steady sweep, the pulse meanwhile becoming much more marked but less rapid.
5 17 30	35	18	
5 17 45	38	19	
5 18 0	38	18–19	From this point the blood-pressure declined gradually until the rabbit died, the pulse becoming very faint—too faint to be counted.
5 18 15	30	18	
5 18 30	25		
5 18 45	22		
5 19 10	20		

In this experiment the effects of poisoning by vanadium upon the circulation appear to have been (1) to cause a steady rise of blood-pressure from 22 millims. to 38 millims., which took about 1 minute to develop, followed by a steady fall, death supervening when the pressure had attained its previous level; (2) to cause a decline, first of all in rapidity, and afterwards in vigour, of the pulse, which developed first suddenly (from 37 per 10 seconds to 26 per 10 seconds in the space of 15 seconds), but afterwards more gradually.

Exp. LI.—June 23, 1874.

Rabbit.—Weight 2465 grms.

Dose ·5 cub. centim. of the 5 per cent. solution (25 milligrammes V_2O_5), injected into the right external jugular vein.

Time.	Mean B. P.	Pulse in 10 seconds.	Remarks.
h. m. s.			Preparations as in Exp. L.
3 5 0	. .	. .	·75 cub. centim. of a 1 per cent. solution of curare injected into the vein. Artificial respiration commenced.
3 21 20	109	50	
3 22 22	. .	. .	Commenced to divide cord.
3 22 28	160	34	Rise due to insertion of knife into cord.
3 22 32	. .	. .	Division of cord complete.
3 22 35	132	45	Blood-pressure began to fall, but rose again (owing to irritation by bleeding?) to 146 millims.
3 22 55	146		
3 25 30	52	40	Blood-pressure again fell suddenly, and continued at 52 millims.
3 27 0	46	26	The pulse began to get slower.
3 27 20	40	. .	The heart ceased to beat somewhat suddenly, and the blood-pressure sank to 25 millims. at once.
3 27 32	25		
3 28 0	. .	7–12	The heart recommenced to beat with slow but vigorous contractions, and quickly regained rapidity; the blood-pressure rose rapidly and exceeded, at first, its previous level.
3 28 30	75	30	
3 29 55	48	26	The blood-pressure settled at last at about 48 millims.; the pulse did not regain its former rapidity.
3 30 23	48	26	Commenced to inject the vanadate.
3 30 35	48	23	Injection complete.
3 30 45	48	20	The pulse became less frequent and the pressure sank slightly.
3 30 55	46	14	
3 31 5	. .	. .	The heart seemed to stop suddenly, and the blood-pressure at once sank to 30 millims.
3 31 20	30		
3 31 50	. .	8–13	The heart began again just as it had done at 3^h 28^m, and the pressure rose to 95 millims.
3 32 5	95	23	
3 32 10	. .	14	The pulse again became slow, and the blood-pressure fell to 65 millims.
3 32 20	65		
3 32 30	70	20	The pulse quickened a little, and the blood-pressure rose. From this point the blood-pressure sank quite regularly until death supervened. The pulse became too faint to count.
3 33 10	46		
3 34 50	22		

In this experiment the symptoms were complicated by a sudden and momentary stoppage of the heart's action immediately after injection (at 3^h 31^m 5^s), which is not, probably, to be attributed to the action of vanadium, as an exactly similar stoppage had taken place before injection (at 3^h 27^m 20^s). With this exception the symptoms resemble those of the preceding experiment.

Exp. LII.—July 1, 1874.

Rabbit.—Weight 1810 grms.

Dose ·75 cub. centim. of the 5 per cent. solution (37·5 milligrammes V_2O_5), injected into the right external jugular vein.

Time.	Mean B. P.	Pulse in 10 seconds.	Remarks.
h. m. s.			Preparation as in Exp. L., without the loss of any blood.
3 44 0	96	45	Pulse regular ; respiration-curves are well shown.
3 46 30	. .	42	·75 cub. centim. of a 1 per cent. solution of curare injected into the vein.
3 49 30	102	42	Artificial respiration commenced ; pulse stronger.
3 56 0	. .	46	More curare injected.
4 0 0	. .	. .	On raising head to divide cord the blood-pressure rose and fell several times.
4 1 0	110	. .	Rise due to insertion of knife into cord.
4 1 20	124	. .	Cord divided: blood-pressure first rose and then fell, until it stood steadily at 36 millimetres. Pulse of normal depth.
4 6 0	36	30–33	
4 12 30	34	30	Injection of vanadate commenced. About 5 seconds after commencement the blood-pressure began to rise, and reached 71 millimetres by the time injection was completed.
4 12 50	71	28	
4 13 10	64	27	Blood-pressure fell gradually, the pulse becoming less frequent and fainter.
4 13 30	54	26	
4 13 50	62	24	Blood-pressure rose gradually, the pulse still sinking in rapidity and becoming fainter.
4 14 0	60	24	Blood-pressure declined again, and continued to do so until the death of the rabbit, the pulse becoming too faint to be counted.
4 14 30	48		
4 15 0	30	. .	Death.

The symptoms of this experiment resemble in general those of Exp. L. Injection of the poison caused a gradual rise of blood-pressure, followed in succession by a fall, another rise, and another fall, which continued until the death of the rabbit. The pulse became gradually slower and fainter from the moment of injection.

In the following experiment the object was to observe directly the action of vanadium upon the heart after its introduction into the circulation. In order to do this, all the extracardiac circulatory nervous centres were removed in a frog by division of the cord below the atlanto-occipital articulation and destruction of the nervous organs above ; and the heart was then fully exposed to view.

Exp. LIII.—June 30, 1875.

Frog.—Of large size.

Dose ·5 cub. centim. of the 5 per cent. solution (25 milligrammes V_2O_5), injected into the abdominal vein.

Time.	Pulse in 10 seconds.	Remarks.
h. m. s.		
4 5 0	..	Divided the cord at the atlanto-occipital articulation, and destroyed the brain.
4 45 0	..	Tied the frog down on its back: inserted cannula into the abdominal vein for injection. Exposed the heart, avoiding all bleeding.
	9–10	Heart-beats counted directly.
4 50 0	..	Injected about ·25 cub. centim. of the solution. Ventricle seems much dilated and very purple.
	9	Heart-beats not so vigorous.
4 52 0	9–10	Heart-beats rather more vigorous.
4 54 0	..	Rest of solution injected. Ventricle seems very purple: beats less vigorously.
	9–10	Reflex action quite normal on pinching.
4 57 0	7–7·5	Ventricle becomes purple and distended: heart-beats less vigorous.
	7	
4 59 30	7	Heart-beats less vigorous. Ventricle much dilated and purple.
5 4 0	6	Ventricle seems unable to contract so as to drive out the whole of the contained blood.
5 5 30	6–7	
5 8 0	5	
5 10 0	5	
5 11 0	5	
5 21 0	5–5·5	Heart-beats more vigorous.
5 30 0	4–5	
5 33 0	5	Reflex action slight on pinching.
5 38 30	5	Heart-beats weaker.
5 50 0	5	
5 55 0	5	
5 59 0	5	Reflex activity has quite disappeared.
8 30 0	..	The heart went on beating for a long time, exhibiting no other symptoms than a gradually increasing languor. At $8^h\ 30^m$ it was left for the night, beating, but very slowly.

From this experiment we learn that the effect upon the heart of vanadium, when injected directly into blood-vessels, is to cause a diminution in the rapidity and the vigour of its beats.

Résumé of the Action of Vanadium upon the Circulation.

In the preceding experiments the solution containing vanadium was injected either underneath the skin or directly into veins. The results in the latter case were exactly similar in kind to those in the former; but they took place with extreme rapidity, owing to the more concentrated action of the poison.

A consideration of the experiments shows that the influence of vanadium upon the circulation is threefold. In the first place, there is a diminution of blood-pressure, which, however, is not quite continuous, but is marked by intervals in which there is a tendency to regain the former height; these alternate rises and falls take place with considerable regularity. In the second place, there is a disappearance of respiration-curves; and in the third place, there is irregularity and diminution in rapidity of the pulse, which, like the fall of blood-pressure, is not quite regular. In the case of injection into veins there was scarcely time, owing to the rapidity of death, for the development of the marked fluctuations noticed when injection was hypodermic.

The disappearance of respiration-curves can only be due to some alteration of the vasomotor centre, whose oscillations of activity are the cause of them. The marked fall of blood-pressure might be due to one or more of the following circumstances:—1, paralysis of the vasomotor centre; 2, peripheral irritation of depressor nerves; 3, relaxation of arterial tonus due to other causes than vasomotor paralysis; 4, weakening of the heart's action. The alteration of the pulse may be caused by:—1, some action upon the vagi; 2, poisoning of intracardiac centres; 3, poisoning of muscular substance of heart; 4, diminution of blood-pressure. As previous division of the vagi does not seem in the least to alter the circulatory effects of poisoning by vanadium (Experiments XLVIII. & XLIX.), it is clear that none of these effects can be attributed to an action on the vagi. It is, moreover, evident, from experiments detailed elsewhere in this paper, that there is no poisoning of the muscular substance of the heart itself. Further, the fact that vanadium does not paralyze unstriped muscles in other regions of the body (as in the intestines) renders it probable that there is no direct action upon the muscular walls of the arteries. We may therefore at once eliminate both these possibilities from the question. It will be seen on comparison that the fluctuations in blood-pressure and in pulse are only sometimes coincident; neither will, therefore, serve as sufficient explanation of the other, although the effects may be partially due to their interaction. There remains, therefore, the vasomotor system of nerves, with the depressors and the intracardiac nervous mechanism, to which we must look for the chief explanation of the phenomena under consideration. From the experiments in which the cord was divided in the neck, we gather that the effects of vanadium-poisoning upon the pulse occurred as usual, while the diminution and fluctuations in blood-pressure were no longer visible, being indeed replaced by a rise. As in those experiments the vasomotor centre, the accelerators, and the vagus centre and terminations were eliminated (the vagus terminations by means of the curare which was injected), we are driven to the conclusion (1) that the depression and fluctuations of blood-pressure are for the most part due to some action of the poison on the vasomotor centre, and (2) that the irregularities of heart-beats are caused by an affection of intracardiac ganglia. The former conclusion is strongly confirmed by the disappearance of respiration-curves, which must be due to vasomotor mischief, and by the fact that other centres in the cord are acted on by vanadium. Hence it seemed hardly necessary to perform any special experiments after elimination of the depressors. The latter conclusion is fully borne out by

Experiment LIII. on a frog, where the usual diminution followed in a heart which was directly observed after the removal of all extracardiac nervous influences.

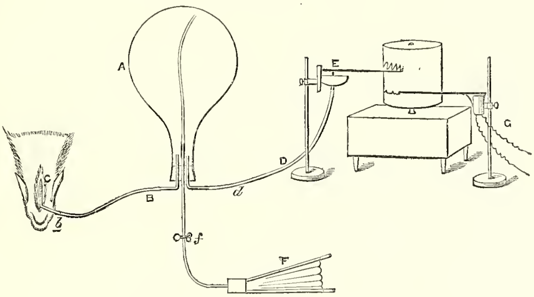
The rise of blood-pressure which follows injection into the veins of rabbits whose cord had been cut is considered to be due to the greater vigour of the heart which was noticed.

IV. SPECIAL ACTION OF THE POISON ON THE FUNCTION OF RESPIRATION.

The following experiments were performed in order to determine the special action of poisoning by vanadium upon the respiratory function.

In the experiments the depth and frequency of the respirations were recorded upon a rotating cylinder, the rate of rotation of which was checked by means of LUDWIG'S Stromunterbrecher and a magnetic marker, in the manner illustrated by the following diagram:—

Fig. 2.



A is a large bolt-head, of capacity equal to 16½ litres, stopped by means of an india-rubber cork fitted with three glass tubes. One of the glass tubes is connected, by means of the caoutchouc tube B, with the glass cannula inserted into the rabbit's trachea, C. Another is connected, by means of the tube D, with a MAREY'S tympanum and pen (E), arranged so as to write upon a SÉCRETAN'S cylinder. The third glass tube is connected on the one side with a flexible tube descending to the bottom of the bolt-head, and on the other with a pair of bellows (F). The object of the pair of bellows is to enable the operator to remove completely all traces of respiratory carbonic acid, and thus to avoid the fallacies introduced by its presence.

After every few minutes in the course of an experiment the tube D was occluded at *d* by means of a clip, the tube B was disconnected at *b*, and the clip at *f* was removed. A few blasts from the bellows then sufficed to thoroughly clear the bolt-head of all the products of respiration; after which the previous conditions were resumed, and the experiment proceeded with. G is the electro-magnetic pen connected with LUDWIG'S Stromunterbrecher.

Both injection under the skin and injection into veins were made use of.

Exp. LIV.—May 6, 1874.

Rabbit.—Weight 1760 grms.

Dose* about 5 cub. centims. of the 5 per cent. solution (250 milligrammes V_2O_5), injected under the skin.

Time. h. m. s.	Respirations in 10 seconds.	Remarks.
12 15 0	. .	Tracheotomy: insertion of glass cannula into trachea.
12 18 0	10	Normal prior to injection.
12 19 0	10	Do. do.
12 22 40	. .	Injection commenced.
. .	11	
12 26 30	12	
12 27 0	. .	Injection complete.
12 29 0	11	
12 30 0	12·5	
12 33 0	15	
12 35 0	17	Respiration shallow.
12 40 0	23	Do. very shallow.
12 42 0	22	Do. do.
12 44 20	17	Do. do.
12 46 0	20	Do. do.
12 50 0	16	Still shallower than before.
12 52 0	13	Respiration deeper and less regular.
12 55 0	10	
1 0 30	17	Very shallow.
1 4 30	15	Do.
1 9 0	13	Do. Eye sensitive.
1 14 30	13	Do.
1 20 0	11	Do.
1 23 0	3	Gasps. Short, shallow inspirations, followed by longer exspirations. Eye insensitive. Twitching of abdominal muscles. Pupil dilated. Dead.

A post mortem examination made at 1^h 30^m showed that the right and left auricles were beating, that the ventricles also were irritable, and that the right side of the heart was much distended.

From this experiment we learn that injection of vanadate of sodium under the skin causes increase of rapidity, and diminution of depth, of respiration; that the symptoms commenced to develop almost immediately after injection, and had become most marked 20 minutes after injection; that the symptoms abated somewhat, but afterwards became violent again; and that death was accompanied, if not immediately caused, by asphyxia.

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* A little of the solution was lost during injection.

Exp. LV.—May 11, 1874.

Rabbit.—Weight 2000 grms.

Dose about 4 cub. centims. of the 5 per cent. solution (200 milligrammes V_2O_5), injected under the skin.

The rabbit died 30 minutes 30 seconds after injection. Artificial respiration, which was commenced immediately on the cessation of natural breathing, again failed to prolong or restore life (see Exp. XLIV.).

In this experiment the symptoms were in general like those of the preceding one; there was, however, no fluctuation in the intensity of the symptoms.

Exp. LVI.—May 13, 1874.

Rabbit.—Weight 1958 grms.

Dose 5 cub. centims. of the 5 per cent. solution (250 milligrammes V_2O_5), injected under the skin.

Time. h. m. s.	Respirations in 10 seconds.	Remarks.
		Tracheotomy. Insertion of glass cannula into trachea; exposure of carotid artery for simultaneous blood-pressure tracing. (See Exp. XLV.)
1 41 0	14–15	Normals prior to injection.
1 45 0	. .	Injection commenced.
1 47 0	. .	Injection finished.
1 47 20	15	
1 49 30	17–18	
1 53 0	18	
1 55 0	18	
1 58 30	17	
2 0 30	20	Very shallow.
2 3 0	19	Very shallow. Eye sensitive.
2 9 0	13–14	Very shallow indeed.
2 9 30	11	Slightly deeper.
2 10 30	9	Slightly deeper.
2 12 15	12	Deeper, but not of normal depth. Eye slightly sensitive.
2 12 45	10	
2 13 15	8	Very deep—deeper than normal. Abdominal muscles convulsed.
2 15 15	12	Shallower.
2 16 0	8–9	
2 16 15	. .	Struggles, which render respiration deep, irregular, and less frequent.
2 18 30	10	Moderately deep.
2 19 0	8–9	
2 20 0	9	
2 20 30	9	Moderately deep.
2 21 0	7	
2 22 0	. .	Death supervened suddenly, preceded by a few shallow gasps.

This experiment agrees exactly with the preceding one.

Exp. LVII.—May 19, 1874.

Rabbit.—Weight 1347 grms.

Dose 5 cub. centims. of the 5 per cent. solution (250 milligrammes V_2O_5), injected under the skin.

The rabbit died within 15 minutes after injection.

This experiment agrees with the preceding, except that the symptoms came on with remarkable rapidity; possibly the injection-syringe punctured some considerable vein (see the experiments on direct injection).

In the following two experiments injection took place directly into a vein.

Exp. LVIII.—June 15, 1874.

Rabbit.—Weight 2430 grms.

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes V_2O_5), injected into the right external jugular vein.

Time.	Respirations in 10 seconds.	Remarks.
		Tracheotomy. Insertion of glass cannula into trachea; exposure of carotid artery for simultaneous blood-pressure tracing. Insertion of cannula into vein for injection.
h. m. s.		
12 13 0	10	Normal prior to injection.
12 15 0	9	Injection commenced. Respiration not so deep.
12 15 15	17	Injection finished. Respiration very shallow indeed.
12 15 30	39	Extremely shallow.
		Rabbit commenced to struggle, rendering respiration irregular and deeper.
12 16 15	12	About normal depth.
12 16 30	12	Rather shallower.
12 18 45	9	Very irregular in depth, owing to the almost incessant and violent struggles of the rabbit. Convulsions and tonic spasms of the lower limbs.
12 19 0	. .	Eye insensitive; pupil largely dilated.
12 20 0	3	A succession of shallow gasps. Dead.

The cord and brain were exposed the whole length, and appeared to be quite normal.

In this experiment the general symptoms were the same as in the case of hypodermic injection, except that they were much more rapid. Within 15 seconds of the commencement of injection respiration was becoming much more rapid and shallow, and the maximum of rapidity and shallowness was attained within 30 seconds of the commencement. From this point respiration declined until death, which occurred amid a succession of gasps.

Exp. LIX.—June 15, 1874.

Rabbit.—Weight 1184 grms.

Dose 1 cub. centim.* of the 5 per cent. solution (250 milligrammes $V_2 O_5$), injected into the right external jugular vein.

The rabbit died within 4 minutes 45 seconds after injection.

The symptoms in this case were substantially the same as in the preceding experiment.

In the next experiment an attempt was made to discover the effect of poisoning by vanadium upon respiration after section of the vagi.

Exp. LX.—May 11, 1874.

Rabbit.—Weight 1235 grms.

Dose 5 cub. centims. of the 5 per cent. solution (250 milligrammes $V_2 O_5$), injected under the skin.

Time.	Respirations in 10 seconds.	Remarks.
		Nervi vagi exposed. Tracheotomy. Insertion of glass cannula into the trachea.
h. m. s.		
2 45 0	8–10	Normal respirations, somewhat irregular.
2 51 0	. .	Vagi divided.
2 53 30	6–7	Respirations after section of vagi deeper than before. Struggles of rabbit.
2 56 0	. .	Injection commenced.
2 57 15	. .	Injection complete.
2 58 0	8	Rather shallower.
3 0 0	6–7	Slightly deeper. Struggles of rabbit.
3 0 30	8	Slightly deeper.
3 1 0	9–10	Rather deeper.
3 2 0	9	Much shallower.
3 3 0	3–5	Very irregular and more like gasps.
3 5 0	. .	Short, sharp gasps at long intervals.
		Pupil insensitive and much dilated.
3 7 0	. .	Dead.

In this experiment the injection of vanadate of sodium beneath the skin of a rabbit whose vagi had been divided previously caused a distinct shallowness and increase in rapidity of respiration, as in the case of rabbits whose vagi were intact; but the alterations were not, proportionally, so great in the former as in the latter case.

Résumé of the Action of Vanadium upon Respiration.

From the experiments just detailed we learn that the action of vanadium, in the form of sodium vanadate, upon respiration is to cause coincidently increased rapidity and diminished depth, which proceed regularly until the period of the greatest intensity of the symptoms is reached, after which the characters of respiration again become normal. Respiration then declines until death, the decline being gradual in some cases, but marked in others by periods of increased vigour and frequency. Death seems to be proximately caused by failure in respiration. There are, therefore, (1) a stimulation and (2) a depression of respiration, which may result either from some lesion of the respiratory centre in the medulla, or from some affection of the afferent respiratory nerve—the vagus. As the usual respiratory symptoms seem to follow after section of both nervi vagi, we must assume the disturbance of respiration caused by vanadium to be centric.

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* A small quantity escaped during injection.

V. SPECIAL ACTION OF THE POISON ON THE FUNCTIONS OF THE MUSCULAR AND NERVOUS SYSTEMS.

In the following experiments frogs were the animals chiefly used, the common *Rana temporaria* being caught from time to time in the neighbouring ponds for the purpose. The minimum stimulus required to produce movement in a muscle was the test made use of. A Du Bois-Reymond's induction-machine was used in stimulation, the coils being gradually approximated until the feeblest contraction occurred, and the distance between them then noted. Interrupted currents were generally used, but single induction-shocks were sometimes resorted to.

The next seven experiments were devised to show the action of vanadium upon the motor and sensory powers of the nervous system and upon muscles.

Exp. LXI.—May 19, 1874.

Frog.—Weight 25 grms.

Dose 1 cub. centim. of the 5 per cent. solution (5 milligrammes V_2O_5), injected under the skin.

h. m.

1 45. The femoral artery of right leg exposed and ligatured a little way above the middle of the thigh. Injection complete; lively; jumps about.

1 50. Lies down, with ligatured leg spread out.

1 52. Drags ligatured limb.

2 23. Lies quiet; moves spontaneously.

2 30. Both legs lie spread out. On touching the ligatured leg the frog kicked twice with the other.

On pinching the non-ligatured leg both legs were moved, but not so vigorously as before.

On pinching the right arm both legs moved, but the ligatured one first.

3 30. Quite dead. Rigor mortis appears to have commenced.

Exposed the sciatics of both legs quickly.

1 Leclanché's element. Interrupted currents.

Non-poisoned limb.	Distance between primary and secondary coils.		Poisoned limb.
Just moves.	25	25	Just moves.

In this experiment no difference in the behaviour of the non-poisoned and of the poisoned legs could be detected, either in the case of voluntary stimuli before death, or of electrical stimuli after death.

Exp. LXII.—May 19, 1874.

Frog.—Weight 28 grms.

Dose ·5 cub. centim. of the 5 per cent. solution (25 milligrammes V_2O_5), injected subcutaneously.

The frog was arranged as in the preceding case, the nerves being tested, as before, as soon as reflex activity had ceased.

In this experiment the motor and sensory nerves of both poisoned and non-poisoned limbs were affected in exactly the same way as indicated by the movements which followed on pinching both legs. The nerves (motor) of both limbs responded equally easily to electrical stimuli after death.

Exp. LXIII.—May 19, 1874.

Frog.—Weight 28 grms.

Dose 1 cub. centim. (about) of the 5 per cent. solution (about 50 milligrammes V_2O_5), injected subcutaneously.

h. m.

4 50. The femoral artery of the right leg was tied close up to the pelvis.

Injection of vanadium solution complete. Quite active.

5 10. Moves on being irritated; also spontaneously, but with a dragging movement.

The frog was noticed at intervals during the next two hours, and exhibited the same phenomena as the last two had done, *i. e.* there did not appear to be any difference in behaviour between the poisoned and non-poisoned limbs.

7 7. Dead to all appearance.

Exposed sciatic nerves quickly. On cutting the skin of the left (poisoned) leg to expose the sciatic nerve, a slight reflex movement took place. Single induction-shock.

Non-poisoned limb.	Distance between coils.		Poisoned limb.
Just moved.	23	21	Just moved.

The muscles were then directly stimulated with single shocks.

Non-poisoned limb.	Distance between coils.		Poisoned limb.
Just moved.	12	12	Just moved.

And again with an interrupted current.

Just moved.	10	10	Just moved.

This experiment serves to confirm the results of the preceding one, and shows, further, that the muscles of the poisoned and non-poisoned legs were equally little affected.

Exp. LXIV.—May 20, 1874.

Frog.—Weight 23 grms.

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes $V_2 O_5$), injected under the skin.

In this case the whole thigh, except the sciatic nerve, was compressed firmly by a ligature.

Rather more than half an hour after respiration had ceased, but before paralysis was general, the frog was decapitated, and the sciatic nerves tested as in the preceding cases.

This experiment confirms the results of the preceding ones, showing that the non-poisoned and the poisoned muscles and nerves are equally irritable.

Exp. LXV.—May 22, 1874.

Frog (α).—Weight 29 grms.

Dose ·5 cub. centim. of the 5 per cent. solution (25 milligrammes $V_2 O_5$), injected under the skin.

Frog (β).—Weight 29 grms.

Dose ·5 cub. centim. pure water injected under the skin.

Time.	Frog (α).	Frog (β).
h. m.		
3 30	Injection complete.	Injection complete. Active.
3 45	Very quiet; eyes closed. Moves on being touched. Respiration appears to have ceased.	Quite active.
4 0	Lower jaw hanging.	
	Decapitated.	Decapitated.
4 5	Sciatic of right leg exposed.	Sciatic nerve exposed.
	Movements when the distance between coils is 30.	Movements occur when the distance between coils is 32–35.
	Muscles of right leg irritated directly. Movements occur when the distance is 18.	Muscles of leg directly irritated. Movements occur when the distance is 16–17.
	Inserted the electrodes into the cord. Movements of legs when distance is 20.	Inserted electrodes into the cord. Movements of legs when distance is 24.

The battery consisted of one LECLANCHÉ'S element. Currents interrupted.

This experiment (a modification of the preceding) practically confirms the results previously obtained, the difference in irritability between the two frogs being merely such as might be due to differences in idiosyncracy, or due to the deficient aëration of the blood in frog (α), owing to early cessation of respiration, and not such as ought to be attributed to a direct action of the poison on muscle or nerve.

Exp. LXVI.—May 25, 1874.

Guineapig (α).—Weight 310 grms.

Dose 3 cub. centims. of the 5 per cent. solution (150 milligrammes V_2O_5), injected under the skin.

Guineapig (β).—Weight 400 grms.

Time.	Guineapig (α).	Guineapig (β).
h. m.		
4 20	Injection complete. Runs about basket.	
4 25	Lies on side. Eyeballs sensitive.	
4 26	Convulsions of hind legs.	
	Clonic spasms. Moves on pinching.	
4 28	Gasps and retches; passes urine. Eyeball insensitive. Dead.	Bled to death [guineapig (α) was not bled].
4 29	Gasped.	
4 35	Cord exposed; electrodes inserted. Very slight movements of dorsal muscles with the secondary coil at 0.	Cord exposed; electrodes inserted. Active movements of dorsal muscles with secondary coil at 8–10.
	The sciatic nerve and the muscles gave good contractions on stimulation.	The sciatic nerve and the muscles gave good contractions on stimulation.

A battery of one LECLANCHÉ'S element was used. Currents interrupted.

This experiment loses value from the circumstance that one animal was bled while the other was not. As regards the (sciatic) nerves and muscles, it confirms the experiments on frogs; but, as regards the cord, it seems to show that poisoning by vanadium interferes with the *conductivity* of the cord. But this observation, in the case of a *warm-blooded* animal, must be regarded as having little weight when it opposes observations to the contrary effect in experiments on *cold-blooded* animals.

Exp. LXVII.—May 26, 1874.

Rabbit (α).—Weight 900 grms.

Dose 2 cub. centims. of the 5 per cent. solution (100 milligrammes V_2O_5), injected under the skin.

Rabbit (β).—Weight 890 grms.

Rabbit (α).

h. m.
1 15. Injection complete.
1 16. Quiet.
1 17. Drags hind legs.
1 20. Turns over on to back; drags hind legs. Breathes very quickly.
1 21. Moves on being pinched.
1 22. Gave a little chloroform preparatory to bleeding. Cries, struggles on being chloroformed.
1 23. Bled to death from the neck. Proceedings were taken to test the irritability of cord &c. See below.

Rabbit (β).

2 10. Chloroformed, and bled to death from the neck. The cord &c. of this rabbit were then tested.

The results in both cases are tabulated side by side, for convenience of comparison.

Rabbit (α).	Rabbit (β).
Cord exposed about middle of back. Movements of dorsal muscles with secondary coil at 8.	Cord exposed about middle of back. Movements of dorsal muscles with secondary coil at 8.
Sciatic nerve of right leg induced contractions in the limb on stimulating with secondary coil at 8–10.	Sciatic nerve of left leg was found to be quite irritable.
The electrodes were inserted between two lumbar vertebræ. The legs contracted on passing a current; but, unfortunately, the distance between the coils was not noticed.	The electrodes were inserted just above the sacrum. Contractions of the legs occurred on passing a current with the secondary coil at 8.

A battery of one Leclanché's element was used. Currents interrupted.

This experiment may be said to confirm exactly the phenomena in the case of frogs. The conditions of the poisoned and unpoisoned animals were rendered equal in this case, unlike that of the preceding experiment.

In the following three experiments attention was more particularly given to all those phenomena in which *sensory* nerves played a part, the special object being to determine whether sensory nerves were acted on by the poison or not.

Exp. LXVIII.—June 1, 1874.

Frog.—Weight 36 grms.

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes $V_2 O_5$), injected under the skin.

h. m.
3 30. The right femoral artery has been tied. Injection complete.
3 42. Breathing slight. Abdomen pinched up and contracted. Voluntary movements.

h. m.

3 56. Lies in a curious posture, with its arms folded beneath it. Membranæ nictitantes half closed. Lower jaw beginning to droop. On being turned over on to its back it does not attempt to recover. No throat-movements of respiration.

On pinching each foot the corresponding leg moves, and to an equal extent in each case.

4 0. Moves spontaneously towards a dark corner of the bell-jar.

4 3. On stirring the bell-jar the frog respired, and jumped.

4 10. On pinching either foot it moved *both* legs with equal vigour. The frog leaped away after having its *poisoned* leg pinched. Lies on belly.

4 12. Spontaneous movements.

The frog was taken from the bell-jar and both feet immersed in a 2 per cent. solution of H_2SO_4; both legs moved, but the *poisoned* one first by a second or two. A 4 per cent. solution of H_2SO_4 was taken, and at

4 32. The frog's feet were immersed in it: no movements occurred after they had remained in for 50 seconds.

4 34. No movements occur on pinching all over the body and limbs.

4 40. Decapitated. Irritated the exposed end of the cord; movements in the arms and lower jaw (which had been allowed to remain) with the secondary coil at 8.

4 44. Passed the electrodes down behind the cord for about ½ an inch (with care, so as not to injure the cord); movements followed, on passing a current, when the secondary coil stood at 9.

4 50. Removed the back of the 5th (or 6th) vertebra as carefully as possible; inserted the electrodes into the cord: movements followed with the secondary coil at 11.

4 53. Removed the back of the vertebral arch next below, and inserted the electrodes into the cord; movements followed in the abdominal and thigh-muscles with the secondary coil at 11.

4 55. Removed the back of the arch next below; extension of *both* legs occurred on passing a current with the secondary coil at 11.

5 0. Both sciatics exposed and placed on the electrodes below (as well as above) the level of the ligature on the right femoral artery; equal movements of *both* calves followed with the secondary coil at 21.

5 4. The muscles of both legs were irritated directly, and about equal extent of movement occurred in both poisoned and non-poisoned leg with the secondary coil at 10.5.

From this experiment we deduce the following:—At a time when the vanadium salt had undoubtedly commenced to produce nervous symptoms no indications of any affection of sensory nerves in the poisoned limb could be detected; at least, the indications given by the poisoned limb were exactly such as were given by the non-poisoned limb. There was, however, distinct impairment of reflex excitability, as shown by the strength of acid necessary to produce even a sluggish reflex action; but this impairment was not due to any affection of the afferent or efferent nerves in the leg, and for the reason, given above, that both legs behaved alike. On stimulating the nerves after decapitation (complete paralysis having previously occurred), it was noticed that, although the whole frog appeared somewhat less responsive than usual, no difference could be detected between the poisoned and non-poisoned limbs.

Exp. LXIX.—June 1, 1874.

Frog.—Weight 31 grms.

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes $V_2 O_5$), injected under the skin.

In this experiment, instead of the femoral artery being ligatured, the whole of the structures of the thigh, excepting the sciatic nerve, were compressed by a thread. In other respects it was a repetition of the preceding experiment, and serves to confirm its results.

Exp. LXX.—June 1, 1874.

Frog.—Weight 30 grms.

Dose 1·5 cub. centim. of the 5 per cent. solution (75 milligrammes $V_2 O_5$), injected under the skin of the back.

In this experiment the right femoral artery was tied prior to injection. The frog was examined, as in the preceding cases, after the poison had begun to manifest itself, and with generally confirmatory results.

In the experiments next succeeding the object was to discover the effect of vanadium-poisoning upon the general functions of the cord as a conductor and as a centre of ordinary reflex action. The action of vanadium upon some of the special centres contained in the spinal cord is found in the notes of experiments on circulation and respiration.

Exp. LXXI.—May 27, 1874.

Frog.—Weight 29 grms.

Dose ·5 cub. centim. of the 5 per cent. solution (25 milligrammes $V_2 O_5$), injected subcutaneously.

h. m.

2 33. Injection complete.

2 47. Respiration very slight.

2 50. Throat does not move at all.

2 53. Reflex action follows, on immersing the toes in a 1 per cent. solution of $H_2 SO_4$, in 5 seconds. On being plunged into water it has great difficulty in keeping its head above the surface.

3 3. Reflex action occurred instantaneously on touching the frog's skin with strong acetic acid.

3 33. Abdominal muscles curiously pinched in; sits upright; moves eyelids, but not vigorously, on the cornea being touched; a solution of $H_2 SO_4$ distinctly acid

to taste produces reflex movements, on dipping the frog's toes into it, in from 4 to 5 seconds. A healthy frog, treated in the same manner, contracted its legs after its toes had been immersed in the acid for 2 seconds.

h. m.

4 15. The same acid solution induces reflex movements in 10 seconds.

4 25. Decapitated, and irritated the end of the exposed cord; movements resulted in the leg-muscles as soon as the secondary coil stood at 8.

4 30. A healthy frog had been decapitated and allowed to recover from the shock of the operation; its cord was now irritated in the same way; movements resulted when the secondary coil stood at 11.

4 30. On again testing the reflex irritability of the poisoned frog in the manner above indicated and with the same solution of acid, no indications were obtained, even after the feet had been immersed for 100 seconds.

This experiment indicates a general impairment of the power of reflex action, while the function of the cord as a conductor of stimuli remained intact to all intents, the apparent difference in the degree of irritability of the cord in the normal and in the poisoned frog being most probably due to the deficient aëration in the latter case, a circumstance only indirectly attributable to the poison.

Exp. LXXII.—May 27, 1874.

Frog.—Weight 23 grms.

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes V_2O_5), injected subcutaneously.

h. m.

2 40. Injection complete.

2 55. Respiration seems almost to have ceased; the frog lies quite flat on its belly as if weak. Reflex action, after immersing the toes in a ·1 per cent. solution of H_2SO_4, in 25 seconds.

On being put into a large beaker of water, the frog sank immediately and did not attempt to swim. It can jump quite well, however.

3 0. Reflex actions induced by strong acetic acid after 5 seconds.

3 5. Lies quiet: moves of its own will.

3 7. On touching the cornea the eyelid did not move until after some time. Sluggish movements result on pinching the leg, also on gently rubbing the thigh with the point of a lead pencil.

3 20. On touching the cornea with the points of the electrode of a secondary coil through which strong interrupted currents were passing, distinct movements of the eyelids were observed.

3 30. On lifting up the bell-jar under which the animal had been lying, the frog moved spontaneously. Pinching induces sluggish reflex actions.

A solution of H_2SO_4 (distinctly acid to taste) caused contractions of a reflex character in 5 seconds.

h. m.
3 36. Reflex activity tested as above; movements occurred after immersion for 10 seconds.
3 42. Reflex actions occurred after an immersion of 20 seconds.
3 47. On exposing the cord high up in the back and irritating, distinct movements occurred when the secondary coil was at 17.

In this experiment reflex action was distinctly impaired; but it may be remarked that voluntary movements occurred long after that impairment had distinctly begun; *i. e.* long after reflex irritability had begun to disappear, the cord was capable of *conducting* impressions from the brain.

The remaining experiments on the functions of the cord were tabulated in order to show clearly the diminution in reflex irritability. In all cases the frogs had their cords cut at the atlanto-occipital articulation, and the parts above the points of section destroyed, in order to get rid of their influence. In testing reflex irritability dilute $H_2 SO_4$ was used as a stimulus, the frog being suspended by the head in such a manner as to allow the toes (or feet) to dip below the surface of the acid; the seconds were counted which intervened between immersion and the occurrence of contraction, and taken to indicate the degree of irritability. The frogs in experiments LXXIII., LXXIV., and LXXVI. were poisoned by the injection of sodium vanadate in solution under the skin; the frog in experiment LXXVII. was similarly injected with pure water, and its reflex irritability used as a standard. Experiment LXXIII. is given in detail to illustrate the method; but its results were exactly confirmed by the succeeding experiments, as will be gathered from the brief notes attached to the latter.

Exp. LXXIII.—June 2, 1874.

Frog.—Weight 34 grms.

Dose ·5 cub. centim. of the 5 per cent. solution (25 milligrammes $V_2 O_5$), injected under the skin.

h. m.
June 1. 7 30 P.M. Cord of frog divided and brain destroyed.

June 2:—

Time.	Remarks.	Strength of acid per cent.	Number of seconds between immersion and contraction.	Mean number of seconds.
h. m.				
11 45 A.M.	Normal reflex actions	2	2	
11 50	" " "	1	1	
	" " "	1	1	
11 52	" " "	1	1	
11 55	" " "	·5	3	
	" " "	·5	2	1·2
12 10	Injection complete.			
12 10	Tips of toes immersed	·5	8	
			4	
			4	
			6	
12 15	" " "	·5	4	
			10	6

TABLE (*continued*).

Time.	Remarks.	Strength of acid per cent.	Number of seconds between immersion and contraction.	Mean number of seconds.
h. m.				
12 20 A.M.	Tips of toes immersed	·5	3	
			5	
			3	
			4	
			5	4
12 25	” ” ”	·5	5	
			6	
			5	
			4	
			4	
			5	5
12 35	” ” ”	·5	10	
			7	
			5	
			9	
			5	
			6	
			7	
			7	7
12 49 to 12 52	Only slight movement occurred	·5	11	
	Marked contraction.		10	
			13	
			11	
			10	
			15	
			11	11·5
12 57	No movement at all	·5	100	
	” ” ”	....	100	
1 2	” ” ”	1	60	
1 5	The acid was allowed to cover more of the feet; contraction occurred	1	5	
			4	
			6	
			6	
	Slight movement	....	17	
	No movement at all	....	60	
1 10	Heart exposed and found to be beating, though languidly.			
1 15	After immersing the whole foot in acid, twitches were observed	1	7	
	Again twitches of calf-muscles occurred	1	50	
	No movement at all	1	150	
	Cord exposed in middle of back, and excited; contractions with secondary coil at 15.			
	Decapitated; irritated exposed end of cord; contraction with secondary coil at 10 to 12.			

Exp. LXXIV.—June 2, 1874.

Frog.—Weight 27 grms.

Dose ·5 cub. centim. of the 5 per cent. solution (25 milligrammes V_2O_5), injected subcutaneously.

h. m.
June 1. 7 30 P.M. Cord cut and brain destroyed.
June 2. 4 7 P.M. Injection complete and experiment commenced.

In rather more than an hour reflex activity had ceased.

Exp. LXXVI.—June 3, 1875.

Frog.—Weight 35 grms.

Dose ·5 cub. centim. of the 5 per cent. solution (25 milligrammes $V_2 O_5$), injected under skin.

h. m.
12 30. Cord divided and brain destroyed.
3 40. Injection complete.
In rather more than an hour reflex activity had ceased.

Exp. LXXVII.—June 3, 1874.

Note.—This experiment was made to serve as a standard for the preceding.

Frog.—Weight 25 grms.

Dose ·5 cub. centim. pure water injected subcutaneously.

h. m.
12 30. Cord divided and brain destroyed.
3 35. Experiment commenced.
Reflex activity diminished very slowly.
7 0. Fair reflex movements on pinching or irritating the skin with acid.
Left for the night in a moist chamber. The next day all reflex power seemed to be absent.

It may be noticed that in these experiments, as the parts above the atlanto-occipital articulation were destroyed, the cord alone is concerned in the reflex acts, inhibition of reflex power by the optic lobe (SETCHENOW) being no longer possible.

The Tables based on these experiments, and figured on Plate 45. figs. 1 & 2, show at once the action of vanadium upon the reflex function as compared with the effects of gradual death in a frog under conditions exactly similar, except that it was not poisoned.

With regard to the *conducting* power of the cord for electrical stimuli, these experiments confirm preceding ones in indicating that vanadium does not affect it at all.

The following experiments were undertaken in order to examine more minutely the effects of vanadium upon the contractility of muscle.

Exp. LXXVIII.—June 1875.

Three frogs were taken, two of which were poisoned by the subcutaneous injection of about 1 cub. centim. of a 5 per cent. solution of vanadate of soda (=50 milligrammes $V_2 O_5$).

When paralysis had completely occurred in one frog, it and the non-poisoned frog were decapitated, and the gastrocnemii of each arranged in a PFLÜGER'S myographion, for recording the length of contraction under different loads. The muscles were directly stimulated with single induction-shocks from a Du Bois-Reymond's machine, the opening shock being used. The battery consisted of a single Daniell's element. The maximum stimulus was ascertained in the usual manner, and employed to produce contractions.

The second frog was allowed to remain until five hours had elapsed from the time of injection, and more than three from the occurrence of complete motor paralysis.

The curves obtained by taking the weights of the load as abscissæ and the length of contraction as ordinates were found to be sensibly the same in the case of poisoned and non-poisoned muscles, as is shown in fig. 4, Plate 46.

The experiment was repeated with similar results.

Exp. LXXIX.—June 1875.

In this experiment preparations were made for recording upon a revolving surface the contraction of muscles when directly stimulated.

The arrangements for stimulation resembled exactly those in the preceding experiment.

Three frogs were again taken, and two poisoned by the subcutaneous injection of 1 cub. centim. of a 5 per cent. solution of sodium vanadate (=50 milligrammes V_2O_5). They were allowed to remain until four hours after injection and two hours after complete motor paralysis. They were then arranged in a myograph and weighted with 10 grammes.

Both opening and closing of the primary current were made use of.

The normal frog was decapitated, and allowed to remain for two hours before being tested. The curve of its contraction was then obtained in the above-mentioned manner. Rotation of the revolving surface was checked and time recorded by means of the vibration of a tuning-fork vibrating 100 times per second.

The curves obtained in the cases of poisoned and of non-poisoned muscles were sensibly the same, as is shown in fig. 3, Plate 45.

The experiment was repeated with similar results.

The preceding two experiments are considered to show that vanadium in the form of sodium vanadate does not affect muscular tissue when introduced into the circulation of living animals.

It has been shown in a previous part of this research that the disturbance of circulation and respiration which follow poisoning by vanadium are mainly due to an action of the poison upon their respective centres in the cord. It seems, therefore, of interest to give here, among the experiments relating to the nervous system, some which show the simultaneous action of the poison upon circulation and respiration.

Exp. LXXX.—May 13, 1874.

Rabbit (buck).—Weight 1958 grms.

Dose 5 cub. centims. of the 5 per cent. solution (250 milligrammes $V_2 O_5$), injected under the skin.

Note.—The half of this experiment which refers to the circulation has already been given on p. 524 (Exp. XLV.) with full explanatory remarks; similarly the half referring to the respiration is found on p. 537 (Exp. LVI.).

From the data furnished by those experiments a Table (fig. 5, Plate 46) has been constructed illustrating the simultaneous effects of the poison upon the vasomotor and respiratory centres. The chief points of interest are:—(1) that the line of mean blood-pressure sinks from beginning to end, while the line indicating the rapidity of respiration first of all rises and afterwards sinks; and (2) the numerous irregularities, especially near the termination, indicating the successive revivals of functional activity on the part of those centres.

Exp. LXXXI.—June 15, 1874.

Rabbit.—Weight 2430 grms.

Dose 1 cub. centim. of the 5 per cent. solution (50 milligrammes $V_2 O_5$), injected into right external jugular vein.

Note.—The half of this experiment which refers to the circulation has already been given on p. 527 (Exp. XLVII.) with full explanatory remarks; similarly the half referring to respiration is found on p. 538 (Exp. LVIII.).

The results of this experiment are tabulated in the manner adopted in the last experiment (fig. 6, Plate 46). The remarks there made apply to this Table also, except that the initial increase in rapidity of respiration is in this case more marked; and when once the rapidity has commenced to diminish it does not, as in the preceding experiment, ever increase again. This may, however, have been due to an error in the method of observation (see note to fig. 6, Plate 46).

Résumé of the Action of Vanadium upon the Muscular and Nervous Systems.

In the account of the general action of vanadium upon the animal economy it was noticed that in nearly all animals, when the dose was large, one of the most important symptoms of poisoning was the occurrence of convulsions and paralysis of motion.

The experiments which have just been detailed furnish the explanation of those phenomena.

Frogs were the animals chiefly used. As, however, paralysis was the only form which the nervous symptoms of poisoning took in them, the conclusions drawn apply primarily to those symptoms.

Paralysis of voluntary motion may result from disorder of one or more of four sets of organs. It may be caused by some affection of the motorial end-plates of nerves in muscles, as in the case of poisoning by curare; it may result from some interruption in the conducting apparatus by which impulse to contraction is conveyed from the centre to the muscle, as in the case of lesions of the cord or trunks of nerves due to mechanical or other causes; it may be attributable to some alteration in the central nerve-cell from which the impulse to contraction (proximately) originates; or it may be due to loss of irritability of muscular tissue, as in the case of poisoning by sulphocyanides. In paralysis of reflex motion (which occurs in frogs, but not in other animals) the motor apparatus itself is not necessarily implicated, as such paralysis may be due to an affection of any one of the analogous parts of the afferent system, viz. peripheral organ (of sense), centripetal nerve-fibre, or central cell in which the impulse conveyed from the periphery is reflected. When, however, paralysis of reflex action is accompanied by paralysis of voluntary motion (as in the case of frogs poisoned by vanadium), it is clear that, whether the afferent apparatus be affected or not, there is some disorder of the other series of organs to which reference was made.

In order to obtain the necessary data, comparative experiments of the following nature were carried on:—The femoral artery of one limb of a frog was ligatured, in order to prevent the passage of the vanadium solution, which was injected hypodermically, to the tissues of the leg. Under these circumstances, in which the nerve-trunks and motorial and sensory end-organs were kept from the influence of the poison, it was found that as the poison began to take effect no difference in behaviour between the two legs could be detected. Up to the same moment the same stimulation applied to the skin produced the same amount of motion, and at the same time paralysis of motion occurred in both limbs and all over the body. When paralysis was complete, and the nerves above and below the point of ligature were tested, the same degree of stimulation (practically) was needed to excite the muscles of each leg to contraction, and on comparison with normal frogs it was seen to be just so much as was required to excite the muscles in their case. In the same way no difference was discernible in the behaviour of the muscles of the two legs and of healthy frogs. In all cases similar degrees of stimulation produced the same amount of contraction. Paralysis was therefore not due to any alteration, in the case of reflex activity, of conducting fibres or peripheral organs of either afferent or efferent systems; or, in the case of voluntary motion, of conducting fibres, motorial end-organs, or muscular tissue.

In other comparative experiments two frogs were taken of about the same weight, and one of them was poisoned by injecting vanadium solution underneath the skin of the back. As soon as paralysis of motion was effected both frogs were decapitated, and the cords of each stimulated. The slight differences which were sometimes observed in the degree of stimulus needed to induce contraction were only such as might be attributable to the defect of aëration in the poisoned frog due to the early cessation of respiration. Paralysis was therefore not due to any defect of conducting-power in the cord.

The preceding results were verified, as far as was possible, in the case of young mammals.

The cause of paralysis, therefore, presumably affects the initial cells concerned in the origination or transmission of nervous impressions.

The experiments on the reflex activity of frogs, both with and without the presence of brain (and SETCHENOW'S inhibitory centres in the optic lobes), show a diminution of irritability, which must be attributed to centric disturbance, since afferent and efferent nerves are unaffected.

It is only necessary to allude here to the action of vanadium upon the special centres of the cord. It acts upon the vasomotor centre in such a manner as, in course of time, to release the arterial tonus, and it first excites, and afterwards depresses, the respiratory centre, as is shown in figs. 5 & 6, Plate 46. It may be noticed that the effects of poisoning by vanadium do not increase with regularity. In the case of the reflex, as of the circulatory and respiratory centres, there occur brief, but very well-marked, periods during which functional activity is almost fully resumed before finally succumbing to the poison. This is well shown in figs. 1, 2, 5, & 6, Plates 45 & 46.

With regard to sensibility, no indications were noticed of any defect, either in the experiments on the general effects of poisoning or in the comparative experiments mentioned above.

No cerebral symptoms were seen, except the sluggishness which occurred in all cases of poisoning; and in other respects the animals experimented upon (except frogs, in which the occurrence of general paralysis rendered it impossible to judge) remained apparently conscious until death.

Special experiments were undertaken to discover whether vanadium (an intense irritant poison) was not also a muscle-poison. No indications of its being a muscle-poison could be detected. (See figs. 3 & 4, Plates 45 & 46.)

IV. CONCLUSION.

From the experiments and observations described in this paper it results:—

1. That vanadium is a metal possessed of intense poisonous activity.
2. That it manifests this poisonous activity when a soluble salt (a vanadate) is introduced into the system by the stomach, by subcutaneous injection, or by direct injection into veins.
3. That it interferes with the vital functions of simple organisms.
4. That it destroys the irritability of muscular and nervous tissues when directly applied to them, even in very dilute solutions.
5. That when introduced into the system by the stomach, or subcutaneously, it produces congestive and inflammatory changes in the alimentary mucous membranes.
6. That it exerts no direct action on the blood.

7. That when introduced into the system subcutaneously, it does not affect the irritability of muscle and nerve.
8. That it depresses the temperature of animals poisoned by it.
9. That it slows and finally weakens the action of the heart by acting upon its intrinsic nervous mechanism.
10. That it lowers the blood-pressure by acting
    (*a*) Upon the vasomotor centre.
    (*b*) Upon the heart.
11. That it first quickens, then slows, and ultimately arrests the movements of respiration by acting on the respiratory centre.
12. That it causes convulsions and partial paralysis in higher animals, and in frogs complete paralysis of voluntary and reflex activity, which is of spinal origin.

In conclusion, the author begs cordially to thank Professor ARTHUR GAMGEE for the kindness he has manifested towards him while engaged in this research, and Professor ROSCOE, for his liberality in supplying and supervising the preparation of the necessary reagents.

EXPLANATION OF PLATES 45 & 46.

Figs. 1 & 2 are Tables founded upon Experiments LXXIII.–LXXVII., the results of which they present in a comparable form.

The continuous lines in both figures are curves built upon data obtained from frogs poisoned by subcutaneous injection of vanadate of sodium, while the dotted lines are curves similarly obtained from frogs injected under the skin with distilled water. The method of experiment and the nature of the data are stated on pp. 548–550. (Details of Experiment LXXV. were omitted from the text as unnecessary to the comparison at that stage. The curve of the experiment is, however, retained here for the sake of exactness; for the experiments of fig. 1 were all under conditions which differed slightly from the conditions in the experiments of fig. 2, as may be gathered from the text.)

In the Tables the time is divided into fractions (minutes), which form abscissæ, while the ordinates represent the degrees of irritability. The latter are calculated from the number of seconds intervening between immersion into the acid and contraction. The number 15 was taken arbitrarily as an index of perfect reflex power, indicating instantaneous response to stimulation by the acid. As the number of seconds between immersion and contraction was found by looking at the second-hand of a watch, without any automatic register, all contractions occurring within 1 second of immersion are accounted "instantaneous." Decline of reflex power was manifested by the successively increasing number of seconds intervening between stimulation and response.

The descent of the dotted curve in fig. 2, after the 140th minute, is supposititious, not ascertained, as reflex power departed during the night (see Exp. LXXVII. p. 550); but the descent is probably overestimated, *i. e.* reflex activity declined less rapidly than the diagram indicates.

Fig. 3. Curves of muscular contraction in the cases of a normal frog (b, b') and of two frogs poisoned by subcutaneous injection of vanadate of sodium (a, a' and c, c'), to illustrate Exp. LXXIX., where the method of obtaining them is described.

a, a', with muscles of poisoned frog 4 hours after poisoning. Maximum stimulus was employed (secondary coil close up to primary).

	Making.	Breaking.
Time of whole contraction..............	·11 second.	·11 second.
Time of latent period	·015 ,,	·0075 ,,
Time of maximum contraction	·0725 ,,	·07 ,,

b, b', with muscles of normal frog 2 hours after decapitation. Maximum stimulus was employed (secondary coil close up to primary).

	Making.	Breaking.
Time of whole contraction..............	·105 second.	·105 second.
Time of latent period..................	·0075 ,,	·005 ,,
Time of maximum contraction	·0625 ,,	·065 ,,

c, c', with muscles of poisoned frog 4 hours after poisoning. Maximum stimulus was employed (secondary coil close up to primary).

	Making.	Breaking.
Time of whole contraction..............	·115 second.	·1125 second.
Time of latent period..................	·0125 ,,	·01 ,,
Time of maximum contraction	·08 ,,	·065 ,,

Fig. 4. Curves of muscular work in the cases of a normal frog (b) and of two frogs poisoned by subcutaneous injection of vanadate of sodium (a and c), to illustrate Exp. LXXVIII., where the method of obtaining them is described.

a, with muscle of poisoned frog 1½ hour after poisoning, when paralysis of motion was fully developed. Maximum stimulus was employed (secondary coil 5 centims. from primary).

b, with muscle of normal frog soon after decapitation. Maximum stimulus was employed (secondary coil 5·5 centims. from primary).

c, with muscle of poisoned frog 5 hours after injection of poison, and 3 hours after paralysis of motion was fully developed. Maximum stimulus was employed (secondary coil close up to primary).

Fig. 5. To illustrate Exp. LXXX. The continuous line represents the variation in blood-pressure, the *outside* vertical column of figures at each end of the Table indicating the blood-pressure in millims. of mercury, while the times are given by the row of figures (=minutes) along the bottom of the Table. The dotted line traces the variation in *rapidity* of respiration, the *inside* vertical column of figures at the left end of the Table giving the number of respirations in 10 seconds, while the times, as before, are given by the figures at the foot.

Fig. 6. To illustrate Exp. LXXXI. The explanation of the preceding figure applies to this also.—*Note.* The rise of blood-pressure indicated by the (*) was accompanied by struggles; at the same moment the rabbit's trachea happened to be disconnected from the apparatus for registering respiration (see p. 535); hence it is impossible to say whether or not an increase in rapidity of breathing occurred which should have been recorded at (×).

XXI. *Contributions to the Minute Anatomy of the Thyroid Gland of the Dog. By* E. Cresswell Baber, *M.B. Lond. Communicated by* Dr. Klein, *F.R.S.*

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The thyroid gland is one of those organs, commonly known by the name of ductless or blood-glands, about which our knowledge is still in a very unsatisfactory condition. The function of this body is quite unknown, and its minute structure is still involved in some obscurity*.

Results of previous Investigations.—The present state of our knowledge of the structure of this organ may be gathered from the writings of Henle ('Handbuch der systematischen Anatomie des Menschen,' 1866, vol. ii. pp. 535–541), Kölliker ('Handbuch der Gewebelehre,' 5th ed. 1867, pp. 480–482), Verson (Stricker's 'Human and Comparative Histology,' Sydenham Society's translation by H. Power, vol. i. pp. 370–372), and Frey (Das Mikroskop, 4th ed. 1871, pp. 232 & 283).

According to these authors the thyroid gland consists of numerous vesicles, embedded in, and supported by, a stroma or framework of connective tissue containing blood-vessels, nerves, and lymphatics.

The Stroma.—The stroma is directly continuous with the capsule of connective tissue investing the gland, from which strong trabeculæ pass inwards, dividing the gland into lobes, and from these, again, finer septa originate, which subdivide the lobes into lobules (*Drüsenkörner*, Kölliker). "In this way the thyroid gland of man is divided into primary and secondary segments, the line of division between which is recognizable by slight furrows" (Verson). The connective tissue lying between the several gland-vesicles is, according to the same author, very sparing in quantity, and sometimes even it is difficult to discover between the walls of contiguous vesicles a few fibres accompanying the capillaries. Henle finds that the vesicles are partly separated by fine connective-tissue septa, and are partly in direct contact with one another. "The septa," he further says, "are not only relatively, but absolutely greater between the small vesicles than between the larger ones, which gives the appearance as if the connective tissue were compressed or displaced by a distension of the vesicles."

In structure the stroma consists of ordinary connective-tissue fibrils, with fine elastic fibres and connective-tissue corpuscles. On the surface it also contains fat-cells (Kölliker).

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* On this point the following remark of Henle's is of interest. Referring to the ductless glands, he says (Handbuch d. system. Anat. vol. ii. p. 535):—"Of many of these we believe that we know the ultimate elements and their arrangement. But as long as the function, not only of these elements, but also of the organs themselves, remains an unsolved problem, one cannot but suspect that their anatomical structure contains some hidden secret."

The Gland-vesicles.—The gland-vesicles (*Drüsenbläschen*, Kölliker) of the thyroid gland are described as closed globular bodies, consisting of a very fine homogeneous membrane (*membrana propria*) lined by a single layer of epithelial cells (Kölliker, Henle, Verson). Frey, on the contrary, does not believe in the presence of a *membrana propria.* He thinks that the connective-tissue wall of denser texture, when examined with imperfect methods of preparation, may have deceived earlier observers. Authors differ in their description of the epithelial cells. Henle describes them as a single layer of flattened cells containing circular nuclei, and resembling a layer of epithelium. According to Kölliker they are polygonal, finely granular, transparent cells, each with a single nucleus. Frey, again, alludes to them as flattened, cylindrical, nucleated cells. Finally, Verson, in opposition to Henle, lays stress on the fact that the cells in the fresh condition are always somewhat higher than broad. Accurate measurements of the gland-vesicles and of the epithelial cells are given by the different authors, into a consideration of which it is needless to enter here.

The cavity of the vesicle is described as occupied by a clear viscid fluid (Kölliker and Frey) slightly tinged with yellow, and containing much albumin (Kölliker). Henle speaks of the contents as clear, and becoming converted by the action of alcohol into a firm, somewhat shrunken coagulum.

These authors all allude to the occurrence of a *colloid* material in the vesicles, which they consider a pathological condition. Kölliker, however, found it in new-born children, and Verson "at an advanced age."

The Lymphatics.—Frey, who is the last observer who has worked at these, gives the following account of them, as quoted by Henle (*loc. cit.*):—The large lymphatics covering the capsule of the thyroid gland take their origin from a rounded network which surrounds the secondary lobules. From these there branch off finer arborescent canals for the primary lobules, to surround them with perfect rings or with arches more or less complete. From these, again, a few finer canals dip down among the individual vesicles and end in blind extremities." In 'Das Mikroskop und die mikroskopische Technik,' 4th edition, 1871, p. 283, Frey describes the lymphatics as quoted above by Henle, until he arrives at the statement that "a few finer canals not uncommonly dip down among the individual vesicles." He then stops, and does *not* confirm his statement of their ending in blind extremities.

The object with which the present research was undertaken was a minute investigation of the lymphatics of the thyroid gland of the dog, with a view to rendering more accurate our knowledge of their structure and distribution. In the course of the investigation, however, I found it necessary to study more carefully the vesicular and intervesicular tissue, and was then led to observe certain cells in the latter which have not, as far as I am aware, yet been described. I shall therefore treat the subjects of this paper under two headings:—I. The Lymphatics; and II. The Parenchyma.

I. The Lymphatics.

Methods.—The methods of investigation adopted were the following, viz.:—

1. *Injection with Berlin blue.*—The thyroid gland of a freshly killed dog was injected *in situ* with a solution of Berlin blue, by the method of puncture with a subcutaneous syringe. When the gland was sufficiently injected (the naked eye appearances it then presented are described below), it was removed and hardened, either

a. In methylated spirit only, or

b. First in Müller's fluid, and then in methylated spirit.

When sufficiently hard, portions were embedded and stained and mounted in balsam in the usual way.

2. *Injection with Nitrate of Silver.*—Fresh thyroid gland of the dog was injected in a similar manner with $\frac{1}{3}$ per cent. solution of nitrate of silver in water. The gland was then removed and hardened in alcohol, and portions of it were treated as before. Throughout this research the thyroid glands examined were those of adult dogs only.

Characters and Distribution.—The lymphatics of the thyroid gland, when examined by the above methods, presented the following characters.

1. *Macroscopic Appearances.*—The thyroid gland in the dog, as is well known, consists of two separate portions, situate on either side of the trachea and in front of the vertebral column. On inserting the nozzle of a hypodermic syringe into one of these glands, and injecting Berlin blue solution, the following appearances presented themselves:—

The whole gland swelled up, and a fine network of injected vessels appeared on the surface of the organ, which could be distinctly seen with a hand-lens. At the same time lymphatic vessels became injected running from the gland, and these were distributed in the following manner:—Several branches came off from the lower and inner extremity of the gland. These soon joined to form a single vessel, which, running in a direction obliquely downwards and inwards in front of the trachea, entered a small lymphatic gland situate in the median line over about the sixteenth ring of the trachea. The vessels emerging from the upper part of the thyroid gland, which were larger and more numerous than the preceding, formed a plexus immediately above it; and from this there came off two principal branches, the one running upwards and inwards over the front of the windpipe, the other taking a course outwards and upwards and terminating in a large lymphatic gland situate under the upper part of the sterno-mastoid. This gland became partly injected with the Berlin blue. In size it nearly equalled the thyroid gland itself.

On examining with a hand-lens the surface of a thyroid gland that had been injected in a similar manner with nitrate-of-silver solution, a fine network of lymphatics was also seen, resembling somewhat in shape and distribution those to be afterwards described in the interior of the organ (Plate 47. fig. 3).

2. *Microscopic Appearances.*—Before describing these it will be necessary to say a few words with regard to the general structure of the thyroid gland of the dog, as I

have observed it in specimens prepared by the above-mentioned methods, in order to render the descriptions that are about to follow intelligible.

First, with regard to the *stroma*. In the dog, as above mentioned, the thyroid gland consists of two separate portions. Each of these forms apparently a single lobe, which is divided into lobules, more or less distinctly, by processes of connective tissue passing inwards from the surface of the organ, where they are continuous with the connective-tissue capsule surrounding the gland. These bands of connective tissue run chiefly with the blood-vessels, and gradually diminish in size, till between the individual vesicles it is often impossible to say that there is any stroma present. On the whole the connective-tissue stroma appears very sparing in quantity in the thyroid gland of the dog.

The Vesicles.—Between the different ramifications of the stroma are seen the vesicles with their walls, consisting of a single layer of cells arranged like an epithelium, and usually known as "epithelial cells." These commonly present a square or wedge-shaped outline, though their shape varies in different preparations and in different parts of the same specimen. They are usually higher than broad (Plate 48. figs. 8, 13); sometimes, however, they present a more or less flattened appearance, probably the effect of the reagents (Plate 47. fig. 1). Under certain circumstances these cells present a more or less triangular outline, of which more hereafter. Their cell-substance is finely granular, and they are each provided with a single spheroidal nucleus. With regard to the existence or not of a *membrana propria* outside the epithelial cells, I am not in a position to make any definite statement. I may, however, draw attention to the following appearance which I have noticed once or twice in these preparations. In a vesicle where the epithelial cells are partly deficient a distinctly marked line, which occupies the curved *inner* aspect of the epithelial layer, is directly continued onwards in the same direction, for a distance of at least two or three cells, beyond the point where the cells cease to be present. This gives an appearance as if there were a distinct membrane lining the inner aspect (or summits) of the epithelial cells, those that are deficient seeming to have become separated from it. This appearance, however, is probably produced by a layer of hardened secretion adhering to the cells. As mentioned by VERSON (*op. cit.* p. 371), in the dog the walls of the vesicles are frequently seen to be inflexed, forming projections into the cavities of the vesicles.

Contents of the Vesicles.—The contents of the vesicles consist, in addition to a small quantity of a pellucid substance sometimes present, of a peculiar material which shrinks away from the walls of the vesicle and forms a solid mass in the centre. In sections stained with picrocarminate of ammonia it appears as a finely granular substance of a more or less bright yellow hue, contrasting with the red colour of the walls of the vesicles. In specimens coloured with hæmatoxylin, on the other hand, it presents the appearance of an opaque, grey, or greyish-violet mass, which is generally uniform, but sometimes finely granular, in appearance.

From a careful examination of sections of the thyroid gland prepared by the above methods, the characters and distribution of the lymphatics within the gland were found to be as follows:—

Traversing the gland, chiefly in a longitudinal direction, and accompanying the larger blood-vessels and septa of connective tissue, are numerous *lymphatic vessels* of considerable size. They not uncommonly surround the arteries which they accompany, as represented in Plate 47. fig. 1, and even completely invaginate them, so as to represent "perivascular lymphatics" (see fig. 5). These vessels are in direct connexion with the network of lymphatics already described on the surface of the organ (see p. 559). They are provided with valves; and their walls are formed by a layer of endothelium, the cells of which are elongated and have a somewhat sinuous outline. Many of these cells appear to be provided with two, or even three, oval-shaped nuclei (see fig. 7). The endothelial markings are well seen in specimens prepared according to method 2, and the nuclei sometimes assume a faint violet tint from the hæmatoxylin.

As represented in figure 7, the nuclei are not uncommonly seen as if lying under the silver line separating two adjacent cells, a part of the nucleus being on one side of the line and part on the other.

Coming off from these vessels, and traversing the gland in all directions, are *numerous lymphatic tubes* of very varied size and shape. The larger ones run principally between groups of vesicles, and are in direct communication with smaller ones which pass between individual gland-vesicles. The latter (the "few finer canals" of FREY), in a well-injected specimen, are seen to be numerous, and are frequently noticed partially, and not uncommonly completely, surrounding the individual vesicles. As mentioned, these tubes vary very much in size and form—in fact, they appear to adapt themselves accurately to the intervals left between the vesicles. This being the case, as might be expected, the diameter of a tube rarely remains constant for any distance; and where the intervals left between the vesicles are larger, the tubes expand into *lymphatic spaces* having the most irregular shape.

The lymphatic tubes, then, both large and small, together with the lymphatic spaces, form a dense rounded network of freely anastomosing canals, which permeates the entire substance of the thyroid gland. In *no case have I seen any indication of the lymphatics terminating in blind extremities*, and can only attribute such an appearance to an imperfect injection. The distinctly tubular character of the tubes, as well as the form of the spaces and tubes generally, are best seen in specimens injected with Berlin blue (figs. 2 & 3). In perfectly injected parts of silver preparations a continuous layer of endothelial cells is seen lining both larger and smaller lymphatic tubes and lymphatic spaces. Figs. 4 & 6 represent lymphatic tubes and spaces lined by the endothelium, which in some places has been accidentally cut away.

The endothelial cells are somewhat elongated, and present an irregularly sinuous outline. They form a delicate membrane, adhering closely to the outer wall of the vesicles. In a thick section this can be well seen following accurately the walls of the vesicles, and covering them, as it were, like a thin veil. (Attempts to represent this disposition of the endothelial membrane are seen in figs. 5, *c*, & 6.) In these silver preparations a frequent appearance is that of a small artery traversing a lymphatic, and completely surrounded by a layer of endothelium, as represented in fig. 5, *b*.

Once familiar with the appearances in preparations in which the silver injection has been successful, the walls of the lymphatic tubes and spaces may be recognized between *almost all* contiguous gland-vesicles in parts where the injection has not penetrated.

They appear in this case as two fine dark wavy lines, studded at intervals with the nuclei of the endothelial cells seen in profile (figs. 13, 14, &c.). The nuclei then appear as staff-shaped bodies, and are of a much darker colour than when seen from their broad surface. The walls of the lymphatics presenting this appearance can usually be seen extending quite up to the free extremity of the inflexions mentioned above (p. 560). Where two vesicles are in apposition, it is not uncommon to see the two dark lines representing the opposite endothelial walls separated for a short distance by a small quantity of a transparent material.

It is possible that this appearance, attributed to the lymphatics, may *in some instances* be produced by capillary blood-vessels. Judging, however, from specimens in which the lymphatics are injected, it is probable that we have to do with such vessels, although it is not possible to distinguish the nucleated membrane forming the wall of a capillary blood-vessel from that of a lymphatic.

The Contents of the Lymphatics.—Before concluding this description of the lymphatics I must say a few words with regard to the contents of these vessels.

On examining the lymphatic vessels in a specimen injected with Berlin blue, and stained with picrocarminate of ammonia, by far the greater part of their cavity is seen to be filled with a granular material of a more or less bright yellow colour. The blue injection occupies the peripheral portion of the lumen of the vessel, forming bands of colouring-matter between the wall of the vessel and its contents. In fig. 1, *b* represents the granular contents of a lymphatic vessel, and the dark line surrounding this indicates the position of the injection. On examining the lymphatic tubes some of them are seen to contain this granular material; the greater part, however, in a well-injected specimen, are filled with blue injection. It is probable that the injection first entering the smaller tubes, *i. e.* the rootlets, forces their contents, or at least a part of them, onwards into the larger tubes, and from these into the lymphatic vessels. From the relation existing between the injection and the contents of the vessels, I am led to the belief that during life the contents are of a *viscid consistence.* This conclusion results from the following considerations:—If at the time of the injection the contents were fluid, or of the consistence of ordinary lymph, the injection on entering the vessels would either force the contents of the same before it or commingle with them. The injection, however, was performed *immediately* after death, before the contents could have had time to coagulate; and the injection, as we have seen, does *not* mix with the contents, but forms a separate layer between them and the wall of the vessel. It therefore follows that the contents of the lymphatic vessels must during life have been more or less viscid in character.

In sections stained with hæmatoxylin the contents of the lymphatics usually present a uniform appearance, but are sometimes finely granular. They stain of a faint greyish-violet colour.

In addition to this peculiar material, a few globules of a hyaline substance sometimes appear in the lymphatics.

II. Parenchyma.

Besides the stroma, lymphatics, blood-vessels, &c. between the vesicles, there is another tissue, to which, as far as I am aware, no allusion is made by authors on this subject.

To this tissue I propose to give the name of "parenchyma," on the supposition that it is possibly analogous to the parenchyma of the testis as described by Kölliker, Henle, and Michalkovitch.

Characters of the Parenchyma.—On examining with a high power (as Vérick's obj. 8) specimens stained with hæmatoxylin and mounted in balsam, the attention is attracted by numerous cells differing markedly in size and shape from the epithelial cells amongst which they lie.

These cells present usually a more or less rounded appearance, and are considerably larger than the adjacent epithelial cells. Their cell-substance is finely granular, and they are each provided with a single large nucleus.

It frequently happens that these cells present an irregular outline, being at the same time smaller, as if the cell-substance had shrunk up round the nucleus. When this is the case a space is left between it and the surrounding structures (*vide* figs. 8, *b*, 10, *b*, 11, *b*, 12, *b*, 14, *b*, and 15, *b*). At some parts of the specimens, however, this is not the case, and the cell-substance then presents a regular rounded outline, and is in contact with the neighbouring elements (*vide* figs. 9, *c* & 12, *c*).

The nuclei of the parenchymatous cells are round or oval in shape, and have a well-marked outline. They are larger than those of the epithelial cells, and do not stain quite so darkly with hæmatoxylin. In their interior are seen several nucleoli.

The parenchymatous cells are met with either alone (figs. 8 & 13) or in groups (figs. 9, 10, 11, 12, 14, & 15). In the latter case several (often three) frequently appear to be situate in a common cavity, which they do not fill out, as shown in figs. 10, 11, & 14. As regards the *position* occupied by these cells, and their relation to the walls of the vesicles, *four* different appearances at least are presented:—

1. The cells are situate, either singly or in groups, *external* to the vesicles, and separated from their cavity by a layer of *normal epithelial cells* (*i. e.* epithelial cells as described above at page 560). See figs. 10 & 15.

2. Other parenchymatous cells, also situate in the intervesicular spaces, are seen to be separated from the cavity of the adjoining vesicle by a layer of *flattened epithelial cells*, the latter presenting a concave surface to the parenchymatous cells. See figs. 8, 9, & 11.

3. Some parenchymatous cells are seen encroaching on the layer of epithelial cells to

such an extent that they are only separated from the cavity of the vesicle by a *thin membrane* (figs. 12, *c* & 9, *c*). They lie, as it were, in a cup formed by the flattened epithelial cells.

4. In other cases the parenchymatous cells are seen lying in a cup or hollow formed by the epithelial cells, and in which the flattened epithelial cells, or the membrane, separating the parenchymatous cells from the cavity of the vesicle have given way, thus placing the parenchymatous cells in *direct communication* with the contents of the vesicle (figs. 12, *b*, 13, *b*, & 14, *b*). In this, as in all other situations described, the parenchymatous cells may be single or several together, apparently in a common cavity.

Lastly, rounded cavities or cups, similar to those shown in figs. 12, 13, & 14, whose walls are formed by flattened epithelial cells, and which communicate freely with the vesicle, may be frequently seen in *an empty condition.*

The simple and, as it appears to me, the only reasonable interpretation of the above facts is this:—The parenchymatous cells, either in groups or singly, lie originally in the intervesicular tissue, outside the epithelial walls of the vesicles. They begin to make their way into a neighbouring vesicle by pressing on the epithelial wall of one with which they are in contact. This pressure exerted by a parenchymatous cell causes the epithelial cells to lose their quadrilateral outline, and to present a more or less triangular or crescentic appearance. The pressure continuing, the epithelial cells become flattened, and finally either separate at once (figs. 13, *b* & 14, *b*) or first become reduced to a thin membrane, which then gives way (fig. 12, *b*). In either case the result is the same. The parenchymatous cell is placed in direct communication with the contents of the vesicle, and can escape into the cavity of the same. And that it does so is shown by the fact that these cups or hollows formed by flattened epithelial cells are frequently seen in an empty condition, having lost their parenchymatous cells.

To sum up this process: it appears that *the cells forming the parenchyma of the thyroid gland of the dog originate in the intervesicular tissue external to the walls of the vesicles; from some cause (inherent movement, or growth of cells behind them) they exert pressure on the wall of an adjoining vesicle; the cells of this become flattened out or absorbed, and finally give way, allowing the parenchymatous cells to escape into the cavity, and to form a constituent of the contents, of the vesicle*; but what part these cells take in the formation of the contents of the vesicles I am unable to state.

The distribution of parenchyma through the gland appears tolerably uniform, though probably its cells are more numerous between the small than between the large vesicles.

As above mentioned, in some places they are numerous and form groups, whereas in others they appear only thinly scattered on the walls of the vesicles. As I have observed them in all thyroid glands of the dog that I have carefully examined, they must be regarded as normal and constant structures.

The parenchymatous cells can usually without difficulty be distinguished from the small vesicles, which they frequently resemble in size. The former are less highly refractive, and possess a nucleus as above described. In fig. 15 the two are seen represented side by side.

Resemblance between the contents of the Vesicles and those of the Lymphatics.—In conclusion I wish to draw attention to the close resemblance existing between the contents of the vesicles and those of the lymphatics. This resemblance will probably have already struck the reader from the description of these two substances given above (pages 560 and 562).

There are several reasons for considering that the two substances are identical:—

1. *The general Appearance and Staining with Reagents.*—In specimens prepared as above, and stained with picrocarminate of ammonia, they *both* present a granular appearance and stain of a yellow colour, more or less bright. In sections stained with hæmatoxylin they *both* present generally a uniform, sometimes a finely granular, aspect, and stain of a greyish-violet colour.

2. *The Consistence.*—The reasons for considering the contents of the lymphatics to be during life of a *viscid consistence* have already been given (see above, page 562). The contents of the vesicles are (as stated above, page 558) described by Kölliker and Frey as consisting of a clear *viscid* fluid; and, as far as I have seen, there appears no reason to doubt this assertion, though I have not directly proved its accuracy.

From these facts it appears that the contents of the lymphatics are *morphologically identical* with those of the vesicles, and they give a strong reason for suspecting that the two materials are also identical in other respects.

It is of material importance to remember that in all but one or two of the cases which have been examined, most of the vesicles, as well as the lymphatics, contained the material above described; and it is further important to bear in mind that the material in the lymphatics fills and even distends the vessels completely, without containing any formed corpuscles; the material cannot therefore be lymph. Hence it is reasonable to think that one, possibly the chief, function of the thyroid gland is the formation, within the vesicles, of a material which is transferred from these by the lymphatics to the general circulation, there to serve some purpose in the animal economy as yet unknown.

The close relationship existing between the lymphatic tubes and the walls of the vesicles, together with the abundant distribution of lymphatics both within and without the thyroid gland, appear to lend support to this view.

This theory is not novel; for Frey (*op. cit.* p. 232), speaking of the glands formed of closed vesicles, says:—"The vesicles are supposed to form a secretion in their interior from the component parts of the blood, and to pass the same on, when ready, to the blood-vessels and lymphatics for removal." He alludes to this as "a very insufficient explanation." And he may well do so, seeing that he gives *no reason* in support of it; for neither Frey, nor any other author I have consulted, alludes to the contents of the lymphatics, still less to the *identity* (*morphological, at least*) *existing between the contents of the vesicles* (where the material is supposed to be *formed*) *and those of the lymphatics* (by which it is supposed to be *carried off*); nor do they give any other ground in support of this view.

The thyroid gland being a body about whose function we know at present absolutely nothing, any clue likely to throw some light on this subject is of value; hence my reason for introducing the above remarks, which are, of course, still in a large degree conjectural. It will be very interesting to examine the thyroid gland in other animals, and to investigate more closely the nature of this peculiar material, subjects which I propose to pursue.

The above research was made at the suggestion, and under the direction, of Dr. KLEIN, to whom I wish to return my best thanks.

Explanation of the Plates.

PLATE 47.

Fig. 1. From a transverse section of the thyroid gland, injected with Berlin blue and stained with picrocarminate of ammonia. (VÉRICK'S obj. 6, oc. I.)

a. Lumen of an artery, seen in transverse section.

b. Cross section of a large lymphatic vessel that surrounds it. This is seen filled with a granular material, stained yellow in the specimen. The dark outline indicates the position occupied by the Berlin-blue injection.

c. Contents of the vesicles, which present a similar appearance to *b.*

d. Walls of gland-vesicles, the epithelial cells of which are flattened by the action of the reagents.

Fig. 2. Small lymphatic tubes and spaces injected with Berlin blue, from a longitudinal section of the thyroid gland. Hardened in MÜLLER'S fluid and alcohol. (Obj. 6, oc. I.)

Fig. 3. A more general view of the lymphatic tubes and spaces, from a similar specimen. In this preparation the tubes appear somewhat shrunk by the action of the reagents. (Obj. 2, oc. I. Tube drawn out.)

Fig. 4. Lymphatic tubes showing endothelium, from a transverse section of the gland injected with nitrate of silver. In this specimen, which is rather thick, the tubes, which in the drawing appear on one level, are situated on various planes, and frequently dip down among the vesicles. (Obj. 3, oc. III.)

Fig. 5. From a transverse section of the thyroid gland injected with nitrate of silver.

a. Interior of a large lymphatic cut across.

Running across its cavity is seen an artery (*b*) which is surrounded by the endothelial wall of the lymphatic. This endothelial layer is also seen investing the outer surface of the neighbouring vesicles. The structure of these is only represented at one part (*c*). (Obj. 3, oc. III.)

PLATE 48.

Fig. 6. From a transverse section injected with silver, showing lymphatic tubes surrounding a group of vesicles and giving off smaller branches. The endothelial

membrane, which in some places is cut away, is seen investing the outer surface of the vesicles. The structure of the vesicles is not represented, their outlines being indicated by the shading. (Obj. 3, oc. III.)

Fig. 7. From a longitudinal section of the gland injected with silver, showing the wall of a lymphatic vessel. The endothelial cells are seen with their oval-shaped nuclei faintly stained with hæmatoxylin. Some of the cells have two, others three nuclei. Some of the nuclei are seen crossed by the silver lines. (Obj. 3, oc. I.)

Figs. 8 to 15 illustrate the appearances presented by the "parenchymatous" cells of the thyroid gland. They are all taken from sections of the gland hardened in alcohol and stained with hæmatoxylin. All except fig. 11 are drawn with obj. 8, oc. I.

In figs. 8, 10, 11, 12, 13, 14 and 15, *a* indicates the interior of a vesicle, and *b* the parenchymatous cells.

Fig. 8. From a transverse section, representing a small portion of the wall of a vesicle (*a*) with its layer of epithelial cells. A large round parenchymatous cell (*b*) is seen, which has so flattened out two epithelial cells that it has formed on their outer aspect a cup, in which it lies.

Fig. 9. From a longitudinal section, showing several parenchymatous cells (with their cell-substance not shrunk) situate at various distances from the interior of the vesicles (*a a*). Some are separated from the cavity of the vesicle by merely a membrane (*c*), others by flattened epithelial cells, and others, again, by normal epithelial cells. Between *a* and *a* a cavity is seen left between the epithelial cells, out of which a parenchymatous cell has probably escaped.

Fig. 10. From a transverse section. Three parenchymatous cells (*b*) with their nuclei are seen apparently situate in a common cavity, and not encroaching, as far as can be seen, on the wall of a vesicle. Their cell-substance appears shrunk.

Fig. 11. From a transverse section, showing a similar space containing apparently two parenchymatous cells (*b*), one of which presents the appearance of hanging into the space and of being attached to the epithelial cells. (Drawn with obj. 8, oc. III.)

Fig. 12. From a transverse section. A portion of the epithelial wall (*a*) of a vesicle is seen in which are two parenchymatous cells (*b*, *c*). The one (*c*) with its cell-substance not shrunk is apparently still separated from the cavity of the vesicle by a membrane; the other (*b*) exhibits a shrunken cell-substance, which, together with its nucleus, stands in free communication with the cavity of the vesicle (*a*).

Fig. 13. From a longitudinal section of the gland, showing a portion of the walls of three contiguous vesicles (*a a a*). In the wall of one is seen a parenchymatous cell (*b*), with its cell-substance slightly shrunk, which, owing to the flattened epithelial cells surrounding it having separated, stands in direct communication with the interior of the vesicle (*a*). This figure shows well the walls of

the lymphatics, together with the nuclei of their endothelial cells seen in profile (see above, page 562).

Figs. 12 & 13 represent a further stage in the movement of the parenchymatous cells to that seen in figs. 8 and 9.

Fig. 14. From a longitudinal section, showing three parenchymatous cells (*b*), apparently situate in a common cavity. The wall of a neighbouring vesicle has become flattened out, and the flattened epithelial cells have separated, placing the parenchymatous cells in free communication with the interior of the vesicle (*a*).

Fig. 15. From a transverse section, showing parenchymatous cells (*b*) and also small vesicles (*c*). The latter with opaque uniform contents, as above described (p. 560); the former exhibiting a granular cell-substance and large oval-shaped nuclei. The cells separating them, possibly from being shrunk, present almost the appearance of a reticulum.

XXII. *On the Placentation of the Lemurs.* By William Turner, *M.B.* (*Lond.*), *Professor of Anatomy in the University of Edinburgh. Communicated by Professor* Huxley, *Sec.R.S.*

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Prior to the year 1871 naturalists were unacquainted with the form and structure of the placenta in the Lemurs. On the 14th August of that year M. Alphonse Milne-Edwards communicated to the Academy of Sciences of Paris a short memoir, entitled "Observations sur quelques points de l'Embryologie des Lémuriens, et sur les affinités zoologiques de ces animaux"*. In this memoir M. Milne-Edwards stated that he had examined gravid uteri of Lemurs belonging to the genera *Propithecus*, *Lepilemur*, *Hapalemur*, and *Chirogaleus* with the following results. The chorion was almost entirely covered by villi, compactly arranged, constituting a kind of vascular cushion, and forming a placenta which enveloped, as with a hood, almost completely the amnion. He named the placenta "*placenta en cloche*," or bell-shaped placenta. The villi were very bushy in the upper and mid portions of the ovum, and diminished gradually as they approached what he terms the cephalic pole, where they disappeared over a surface of some extent. The caduca uterina was very developed, and presented a corresponding disposition. He found a large sac between the chorion and amnion, which he regarded as the umbilical vesicle. He concluded that the placenta was constructed on a distinct type from that of all other mammals, but was further removed from that of Man, Apes, Bats, Insectivores, and Rodents than from that of the Carnivora,—"car si l'on suppose un instant le pôle caudal de l'œuf du chien envahi par les villosités du placenta, on a presque la réalisation des caractères spéciaux à l'œuf des Lémuriens."

In October of the same year M. Milne-Edwards reproduced this memoir†, but with some important additions and modifications. In *Propithecus*, he said, the vascular cushion formed by the villi resulted from the confluence of a multitude of irregular cotyledons. The middle and upper portions of the mucous membrane exhibited numerous

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[*] Comptes Rendus, 14 Août, 1871, p. 422.

[†] Annales des Sciences Naturelles, October 1871.

irregular anfractuosities, and the surface of the mucosa was hypertrophied, so as to form a caducous layer very analogous to that which, to a very feeble extent, adheres to the discoid placenta of the Apes, the Insectivora, and the Rodents. In the vicinity of the cervix uteri this hypertrophy gradually ceased, and the mucosa became quite smooth. The sac which in his first communication he described as the umbilical vesicle he now recognized to be the "allantois." In the genera *Lepilemur* and *Hapalemur* the placenta was similarly constructed, but the villi were less compact. In *Cheirogaleus* the placenta was also bell-shaped, but extended over almost the entire surface of the ovum.

In these memoirs M. MILNE-EDWARDS, whilst regarding the form of the placenta as peculiar, though approximating to that of the Carnivora, is obviously of opinion that, like the placenta in the higher mammals, it possessed a decidua.

Since their publication, however, M. MILNE-EDWARDS appears to have modified, in a very material manner, his views regarding the placentation of the Lemurs. In a private communication made to Mr. ST. GEORGE MIVART, and referred to by that anatomist in an essay on the zoological rank of the Lemuroidea*, these animals are said to have no decidua, and to possess a diffused placenta. No additional observations are detailed, and no explanation is given of the reason why so decided a change of opinion has been arrived at.

In none of his communications does M. MILNE-EDWARDS enter into the minute structure of the placenta, or refer to the relations of the utricular glands to the maternal part of the organ, or describe the condition of the maternal vascular system. The indefinite position in which, not only the form of the placenta, but its minute structure have been left by the only anatomist who has had the opportunity of examining the gravid uteri of the Lemurs has rendered necessary a reexamination of the organ.

Being desirous of contributing to the solution of this question, I wrote to my friend Dr. ANDREW DAVIDSON, of Antananarivo, Physician to the Court of Madagascar, to whom I had been indebted on a former occasion for valuable specimens in illustration of the zoology of Madagascar, and requested him to procure for me, if possible, some Lemurs in the gravid condition. Dr. DAVIDSON at once most cordially acceded to my request, and engaged a man to go into the forest to obtain the specimens, as these animals do not breed in confinement. As the ordinary mode of preserving the carcasses of small animals by immersion in spirit hardens the tissue and organs so as to interfere with their subsequent microscopic examination and minute injection, I suggested to Dr. DAVIDSON that the abdominal cavity should be opened and filled with dry salt, and the carcasses packed in the same preservative, as I had found from experience that the most minute injections could be made of organs treated in this manner.

On the 4th November, 1875, a box containing six carcasses of gravid Lemurs, preserved according to my directions, reached me. The skins were enclosed along with the carcasses, so that I was able to identify the animals. The animals sent were a specimen of *Indris brevicaudatus*, one of *Propithecus diadema*, and four of *Lemur rufipes*. For the determination of the specific name of the last I am indebted to Dr. GÜNTHER, to whom I sent a skin for identification, as I had not in Edinburgh sufficient materials for comparison. Two of my pupils from Madagascar, ANDRIANALY and RAJAONAH, to whom I have shown the skins, have very kindly given me the native names with their English equivalents. *Indris* is called "Simpona," or the short-tailed; *Propithecus* is "Varika," or the spotted; and *Lemur rufipes* is named "Amboan'ala," or dog of the forest.

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* Proceedings of the Zoological Society of London, 1873, p. 504.

As *Propithecus* is the genus which is more especially described by M. MILNE-EDWARDS, I shall in the first instance relate what I have seen in that animal.

Gravid Uterus of Propithecus diadema.

The uterus of the gravid *Propithecus* was pear-shaped, with the fundus directed forwards in the abdominal cavity. Its length was 4 inches, its greatest breadth 2¼ inches. A pair of slender Fallopian tubes extended outwards from the side of the uterus; but whilst the left tube was 1½ inch from the free rounded border of the fundus, the right was 2 inches, so that the uterus was not symmetrical. Close to the mouth of each tube was a pavilion for the lodgment of the ovary, and this gland was attached to the uterus by a distinct ligament. The right ovary was about the size of a common pea; the left was double the size, and contained a corpus luteum. A well-marked round ligament sprang from the uterus close to the origin of each Fallopian tube, and two broad ligaments, enclosing blood-vessels between their folds, were attached to the sides of the uterus. The vagina, 1½ inch long, was continuous with the wall of the uterus.

When examined externally, the uterus, though not quite symmetrical, yet seemed as if single; but when the cavity was opened into by a longitudinal incision along the posterior wall, it was seen to consist of a corpus uteri and two cornua. The uterus contained a single fœtus, which occupied the corpus uteri and left cornu, which together formed the great bulk of the uterus. The right cornu was no bigger than could contain a hazel-nut, and was so blended with the wall of the enlarged left horn that the demarcation between them was not visible externally. The two cornua freely communicated with the corpus uteri, and a septal fold, half an inch deep, covered on each surface with mucous membrane, marked the plane of demarcation between the two horns.

The free surface of the mucous membrane lining the anterior and middle thirds of the cavity of the corpus uteri and left cornu was thrown, over the greater part of its extent, into numerous shallow convoluted folds, separated by intermediate sulci, constituting "une multitude d'anfractuosités irregulières," as described by M. A. MILNE-EDWARDS*. These folds gave to the mucosa a spongy succulent character. Multitudes of crypt-like recesses were situated on the summits and sides of the folds, as well as at the bottom of the intermediate sulci. Scattered amidst these folds were upwards of twenty irregularly elongated areas of the mucosa, in which the folds and crypts were either absent altogether or much diminished in size and relative numbers. The largest of these areas was about $\frac{4}{10}$ inch in its long diameter, though many were much smaller; they were depressed below the general plane of the mucosa and surrounded by crypts. The mucous membrane covering these areas was not succulent, but smooth; it had not the brownish-yellow colour of the surrounding membrane, but glistened with a bluish tint; it had a tense and, in places, a puckered appearance, not unlike a cicatrix on the surface of the skin. In the posterior third of the uterine cavity the folds on the surface of the mucosa had almost entirely disappeared, and in proximity to the os uteri the membrane was quite smooth and destitute both of folds and crypts.

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* Ann. des Sciences Naturelles, p. 3, Oct. 1871.

The mucous lining of the right uterine cornu was for the most part smooth and free from crypts; but on and near the septum between the two cornua it was folded and subdivided into crypts. It was particularly noticed that the mucosa surrounding the opening of the Fallopian tube into the right cornu was perfectly smooth, whilst that surrounding the opening of the left tube was folded and covered with crypts. The uterus was separated from the vagina by a circular fold, which marked the os uteri, but no special cervix was separated from the general cavity of the corpus uteri.

The crypts were shallow cup-like depressions on the free surface of the mucosa. When examined under magnifying-powers of from 20 to 40 diameters, they were seen to be arranged in groups, which were separated from each other by folds of the mucosa. The crypts in each group were bounded by slender shallow folds of the mucosa, which formed the septa between the individual crypts, and usually had a sinuous direction. When examined with higher powers of the microscope, the walls of the crypts were seen to be formed of an abundantly corpusculated and delicate connective tissue.

As, before opening the uterus, I had injected, with the aid of my museum-assistant, Mr. A. B. Stirling, the uterine arteries with gelatine and carmine, I was enabled to study the disposition of the vessels in the walls of the crypts. Ascending from the deeper part of the mucosa to the crypt-layer were numerous small arteries filled with a red injection, which divided into branches that ended in a compact capillary plexus. This plexus was situated in the connective-tissue walls of the crypts; its vessels had a sinuous course following the curvatures of the crypt-walls. Not only did the capillaries belonging to the crypts of the same group form a freely anastomosing plexus, but the capillaries of adjacent groups also freely anastomosed with each other, so that a continuous plexus was distributed throughout the crypt-layer of the mucosa, which gave to the surface of the injected mucous membrane a bright red colour.

The epithelium had been to a great extent lost from the surface of the mucosa, but at the sides and bottom of the crypts, where it was more protected from injury, it could be seen. The cells were columnar in shape, and set with their attenuated ends on the subepithelial connective tissue, whilst their broad free ends formed a mosaic pattern.

Beneath the crypt-layer of the mucosa the utricular glands were situated. In vertical sections through the membrane the glands were repeatedly divided, so that only short segments of each gland could be seen. Although the stems of the gland-tubes were directed towards the surface of the mucosa, none was seen to open into a crypt. When the free surface of the membrane was examined with a magnifying-power of 45 diameters, the glands were observed to lie for the most part obliquely beneath the crypts, but, instead of opening into them, they converged in considerable numbers towards the depressed smooth areas already described on the surface of the mucosa. Each area that was examined had several annular openings in it, which were the mouths of the glands, and through some of them a plug of epithelium could be seen to project. As the membrane in the smooth depressed areas of the mucosa of *Lemur rufipes* was more translucent than in *Propithecus*, and the relation of the glands to their openings was more distinctly seen in that genus, I shall give in the description of that animal a more detailed account of the arrangement. The vascularity of the gland-layer of the mucosa and of the smooth depressed areas was less than that of the crypts.

When the uterus was opened into, the bag of the chorion, with its enclosures, was found free and quite unattached to the uterine surface; the caudal end of the fœtus was projecting through the os uteri, and the cephalic end was in the uterine fundus formed by the dilated left uterine cornu. The chorion and other membranes enveloping the caudal end of the fœtus were torn away, so that the tail and hind limbs were exposed, but the chorion enclosing the head and thorax was entire. The free surface of the uninjured chorion was traversed by numbers of ridgelets, some of which were in parallel rows, whilst others had more of a reticulated arrangement. Sometimes the ridgelets were closely crowded together; at other times they were separated by well-defined intervals. Although the separation of the chorion from the mucosa did not permit one to see the fœtal placenta in position, yet there could be no doubt that the ridgelets had fitted into the sulci between the folds of the mucosa. When examined microscopically the ridgelets were seen to be divided into villi, the greater number of which were broad leaflets, though many were more filamentous and elongated in form. To some extent also smaller leaf-like and filamentous villi arose from the surface of the chorion between the ridgelets. An occasional irregular patch on the chorion free from villi and ridgelets was seen, which had undoubtedly been in apposition with the smoother depressed parts of the mucosa, and the villi on the rest of the chorion had fitted into the crypts in the mucous membrane. The chorion with its villi possessed the usual structure of this membrane. It consisted of connective tissue, with a layer of cells on the free surface. The torn state of the membrane prevented an injection from being passed into the umbilical vessels; but there can be no doubt that the villi were highly vascular. In M. MILNE-EDWARDS's specimens of *Propithecus* the head of the fœtus presented to the os uteri and the cephalic end of the chorion was smooth in correspondence with the smooth surface of the mucosa surrounding the os; whilst the opposite or caudal end was villous. In my specimen the caudal end of the fœtus was the presenting part; and though the chorion enveloping it was torn away, there can be no doubt that it had been free from villi, for the surface of the mucosa with which it had been in apposition was smooth and without crypts. The opposite or cephalic pole, again, was strongly villous, and the surface of the mucosa in the region of the left Fallopian tube, with which it was in apposition, was not only folded, but subdivided into multitudes of crypts. That the chorion had also been prolonged into the non-gravid horn is evident from the presence of crypts on the surface of a part of its mucosa.

The amnion and allantois were so much injured that it was not possible to ascertain their relations to the chorion. The umbilical cord was 2 inches long, and contained two umbilical arteries and one vein, the latter of which bifurcated as it approached the placenta. The fœtus was well developed, and measured 5 inches from the tip of the nose to the root of the tail. The tail was $3\frac{1}{2}$ inches long. The surface of the body was covered with hair, and the nails were distinct. The incisor, canine, and premolar teeth were erupted, but the molars were concealed by the gum. The fœtus was a male.

Gravid Uterus of Lemur rufipes.

The gravid uteri of the four specimens of this Lemur varied somewhat in size and in the development of the embryos. In the smallest specimen, which I shall name A, the uterus was distinctly two-horned. A single fœtus occupied the left uterine cornu. The length of this horn with the body of the uterus was $3\frac{1}{2}$ inches, and the fundus uteri, which was formed entirely by the left cornu, reached $1\frac{3}{10}$ inch beyond the place of attachment of the left Fallopian tube; the breadth of this horn was $1\frac{1}{2}$ inch. The right cornu was only $\frac{8}{10}$ inch long and $\frac{1}{2}$ inch broad. The other three specimens, which I shall name B, C, D, each contained a single fœtus; in B and C it was on the left side, and in D on the right. In all the uterus was very unsymmetrical in form, owing to the much greater development of the cornu of the side containing the fœtus over the opposite horn. The fundus of the uterus was formed by the gravid horn, which in B projected $1\frac{1}{4}$ inch beyond the place of attachment of the corresponding Fallopian tube, in C $1\frac{1}{2}$ inch, and in D only $\frac{2}{3}$ inch. In B the left cornu and corpus uteri together measured 4 inches in length, and in C $4\frac{1}{2}$ inches; in D the right cornu and corpus uteri were together $3\frac{3}{4}$ inches long. In all three the non-gravid cornu appeared as a short diverticulum from the side of the corpus uteri, with which it freely communicated, a short septal fold, as in *Propithecus*, marking the plane of separation between the two horns. In the four specimens the ovaries were about as large as peas. In A, C, and D the corpus luteum was in the ovary corresponding to the gravid cornu; in B it was in the ovary of the opposite horn. As A was evidently at an earlier stage of development, I shall reserve its description until after I have pointed out the characters of B, C, and D.

In B and D the fœtus lay longitudinally in the uterus, with the head presenting to the os uteri; in C the direction of the fœtus was more oblique, the head, though lying towards the os, being situated near the uterine orifice of the right Fallopian tube. In all three the caudal end of the fœtus was in the fundus uteri formed by the gravid horn. In these specimens the chorion was uninjured. When each uterus was opened into by a longitudinal incision through the posterior wall, the chorion was seen *in situ* in close apposition with the uterine mucous membrane. On gentle traction the chorion could be raised from the mucosa, the ridges on the chorion being drawn out of the sulci and the villi out of the crypts, so that the fœtal and maternal parts of the placenta could be separated from each other without any structure having to be torn through.

In all three specimens the free surface of the uterine mucosa was elevated into folds in a considerable part of its extent, though they were not quite so prominent as in *Propithecus.* Both the folds and intermediate sulci were pitted with multitudes of crypts. The mucosa in the posterior third or fourth of the uterus, extending back to the os, was for the most part smooth and free from crypts. In C a smooth band also extended from the os as far as the non-gravid horn, the mucous membrane of which was also for the most part smooth and free from crypts. A similar smooth patch of some size was seen on the mucosa lining the gravid horn, extending into that cornu from the orifice of the Fallopian tube; in C this smooth surface was ovoid in form, and measured 1 inch by $\frac{6}{10}$ inch; in B and D it was almost circular, and about 1 inch in diameter. But, further, irregularly elongated, depressed, smooth areas, about equal in number and size to those described in *Propithecus*, were scattered within the folded crypt-covered part of the mucosa. These areas were quite free from crypts, and did not have so tense and puckered an appearance as in *Propithecus.* The arrangement and structure of the crypts themselves so closely resembled what I have described in *Propithecus*, that it is unnecessary to repeat the description.

The mucosa of *Lemur rufipes*, from being thinner and more translucent than that of *Propithecus*, was peculiarly well fitted for the examination of the arrangement of the utricular glands. When the free surface of the membrane was examined under low powers of the microscope, the tubular glands were readily seen lying beneath the crypts, but very much fewer in number than the crypts. A few of the glands were very tortuously arranged, but more usually they were almost straight; they occasionally bifurcated in their course, and at times gave origin to short diverticula. None of the glands was seen to open into a crypt. The glands situated beneath the crypts converged in a very remarkable manner to the smooth areas of the mucosa already described, and as a rule the tubes became quite straight, though occasionally a tortuous gland was seen beneath the smooth part of the membrane. The straight tubes ran obliquely for a greater or less distance beneath the smooth area, gradually approaching the surface, on which they opened by annular mouths. Ten, twenty, or even a greater number of glands, varying with the extent of the surface, were seen to open on a single smooth area. Usually the glands opened by independent orifices; occasionally two glands joined together immediately before reaching the free surface, and still more rarely three glands joined and opened by a single large mouth; as a rule, the orifices were directed obliquely to the surface, and bounded by a slender fold of the membrane. The mouths of the glands were often arranged in groups of five or six, and between adjacent groups were patches of smooth membrane in which no openings were visible.

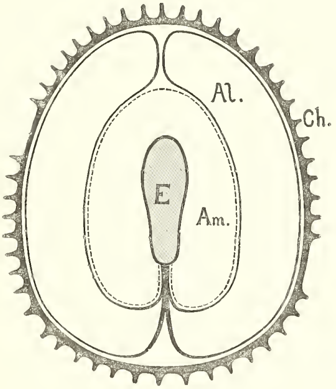
Straight and tortuous glands were seen in considerable numbers beneath the smooth surface of the mucosa surrounding the os uteri, beneath the smooth patch of membrane situated in the fundus of the gravid horn and beneath the smooth mucosa lining the non-gravid horn: in each of these localities the glands opened on the smooth free surface. Quantities of epithelium-cells were contained in the gland-tubes. The cells did not, as a rule, form a continuous lining, but were broken up into separate masses. As a rule, also, the epithelium lining the gland-tube near its mouth was not *in situ*, and that which had formed the covering of the smooth areas was shed. The long interval between the death of the animals and the time of examination, together perhaps with the action of the salt, will, I think, sufficiently account for the loosening of the epithelium-cells in these localities. The number of gland-tubes in the deeper layer of the mucosa was greater than near the surface, so that each gland stem or duct, as it approached the surface, must have received the secretion of several of the deeper tubes.

The chorion occupied the cavity of the corpus uteri and gravid horn, and gave off from the depending part next the os uteri (the so-called cephalic pole of M. A. MILNE-EDWARDS) a short prolongation, having the appearance of a diverticulum, which passed into and occupied the cavity of the non-gravid horn. This diverticulum was best marked in B, in which it measured $\frac{8}{10}$ inch in length; so that the chorion might be described as extending from the tip of one cornu, through the corpus uteri to the tip of the opposite horn. The extension of the chorion into the non-gravid horn had not been recognized by M. A. MILNE-EDWARDS in his specimens; so that whilst he quite correctly regarded that enveloping the caudal end of the fœtus as one pole, he supposed the portion of this membrane which was next the os uteri to be the opposite pole. But the true poles of the chorion are the ends situated in the horns of the uterus, whilst the part covering the head of the fœtus is not a true pole, but the most depending part of the membrane next the os uteri.

The surface of the larger proportion of the chorion was covered by villous ridges, similar to those described in *Propithecus*, and the parts of the chorion in apposition with the smooth surfaces of the mucosa were bare of villi. Thus a bare surface of some size was at the caudal pole of the chorion in the fundus uteri; another bare surface was on the opposite pole in the non-gravid horn, and a still larger bare surface was on that part of the chorion which, enveloping the head of the fœtus, lay opposite the os uteri. The parts of the chorion which were in apposition with the irregularly elongated smooth areas of the mucosa lying amidst the crypt-covered surface were also non-villous. The chorion had the usual structure of that membrane, and its epithelial covering was distinct. I did not succeed in obtaining an injection of the umbilical vessels; but there can be no doubt that the villi were highly vascular; and from what I have seen in other animals possessing a diffused arrangement of the villi over the chorion (*e.g.* Pig, Mare, *Orca*, Narwhal, Dromedary), it is also very probable that a network of capillaries was distributed beneath the intervillous parts of the membrane.

The chorion of C was then cut through by a longitudinal incision, and the sac of the allantois was opened into. It was 4 inches long, and extended from the caudal pole as far as the head of the fœtus, but did not pass into the short diverticulum of the chorion which occupied the non-gravid horn. Opposite the abdominal aspect of the fœtus, where the umbilical vessels passed to the chorion, the outer wall of the sac of the allantois was reflected on to the inner surface of the chorion; and along a line opposite the back and head of the fœtus the allantoic membrane was again reflected on to the outer surface of the amnion, so as to form the inner wall of the sac of the allantois. The sac of the allantois was thus divided into two almost equal parts, one corresponding to each lateral aspect of the embryo; but as the line of reflection opposite the abdominal aspect was not equal to the length of the sac, the two halves on opposite sides freely communicated with each other. The amnion formed a well-defined bag enclosing the fœtus, coequal in length with the sac of the allantois, and, like it, not extending into the short diverticulum of the non-gravid cornu.

Diagram of the arrangement of the fœtal membranes of *Lemur rufipes*, as seen in transverse section through the embryo.



E. Embryo.	Ch. Chorion, with villi and non-villous patches.
Al. Sac of allantois.	Am. Sac of amnion. The dotted line represents the amnion.

The fœtus was well developed, and measured between 5 and 6 inches from the tip of the nose to the root of the tail. The head, instead of being bent forward under the thorax, was twisted round, so that the lower jaw rested on the back. The tail, 4 inches long, was curved under the belly. The hind limbs were flexed at the hip, knee, and ankle-joints; the joints of the fore limbs were also bent. The skin was well haired, and the nails were developed on the digits.

When the uterus of A, the least developed specimen, was opened into by an incision along the posterior wall, the non-gravid cornu was seen to communicate with the corpus uteri $1\frac{2}{12}$ inch from the os uteri. The corpus uteri, for $\frac{1}{2}$ an inch beyond the os, was a narrow tube, in which the mucous membrane was longitudinally folded as in the non-gravid uterus; it then became more dilated, so that the mucous membrane was more expanded, but free from crypts. The mucosa of the non-gravid cornu was quite smooth and without crypts. The gravid left cornu, which measured $2\frac{3}{10}$ inches from the summit of the fundus to the corpus uteri, was dilated and contained the ovum. The mucous lining in close proximity to the corpus uteri was smooth and free from crypts, but for the most part it was folded and subdivided into crypts, as in the other specimens of *L. rufipes.* Extending, however, from the orifice of the Fallopian tube into the fundus was a smooth ovoid surface free from crypts, about 1 inch in its long diameter; and several elongated, depressed, smooth areas, in which the mouths of the glands were seen to open, were situated amidst and surrounded by the crypt-covered folds.

The chorion was ovoid in form, $1\frac{8}{10}$ inch long, and did not pass either into the corpus uteri or the cavity of the non-gravid horn. The broader end of the ovum was situated in the fundus uteri; the narrower end came almost up to the corpus uteri. The surface of the chorion was almost uniformly villous, a small bare patch being situated at the pole directed towards the corpus uteri, whilst a larger non-villous patch was on the pole of the chorion, in apposition with the smooth surface of the mucosa in the uterine fundus. An occasional narrow bare patch also corresponded to the depressed smooth areas on the mucosa already referred to. It is clear, therefore, that the corpus uteri and non-gravid cornu do not become dilated in the earlier stages of development, and that the chorion only grows into them as the development of the fœtus progresses. The proportion of villous chorion to non-villous in this specimen was considerably greater than in B, C, and D.

Gravid Uterus of Indris brevicaudatus.

This uterus, from its small size, was obviously the least developed of the specimens which had reached me. It was distinctly two-horned, and the right cornu was somewhat bigger than the left. The distance from the os uteri to the fundus of the right cornu was $1\frac{3}{10}$ inch, to the fundus of the left cornu 1 inch. Each cornu had attached to it a Fallopian tube, a round ligament, a broad ligament, and an ovarian ligament with its ovary. A corpus luteum was in the right ovary, and in close relation to each ovary was a pouch-like fold of the peritoneum.

The cavity of the uterus was opened into by an incision through the posterior wall. The entrance to the smaller cornu was $\frac{4}{10}$ inch from the os, and the uterine mucosa up to that entrance, which formed the lining of the corpus uteri, was raised into longitudinal folds. The entrance into the more distended cornu was marked by a comparatively broad fold of the mucosa, which ran transversely around the greater part of the mouth of the cornu. The mucous lining of the distended horn was thrown into strong convoluted folds, with deep intermediate sulci: the main direction of these folds was longitudinal; but they were much more tortuous, subdivided, and prominent than those in the corpus uteri.

Unfortunately I did not succeed in seeing the ovum in this specimen. Under the action of the salt in which the carcass had been for so many months preserved after the animal had been shot, the uterus had become so much contracted that it required some hours steeping in water before it was fit for drawing and dissecting. As the ovum could have been in only a very early stage of development, its delicate tissues had probably so shrivelled up that it entirely escaped notice when the uterus was opened. There could, I am sure, be no question that the uterus was gravid, for not only was the one horn more distended than the other, but the folds of its mucous membrane were bigger, much more convoluted and subdivided than is the case with the folds of the mucosa in the non-gravid uterus.

General Observations on the Placentation of the Lemurs.

Several eminent zoologists, in classifying the Mammalia according to their placental characters, have placed the Lemurs, along with the Insectivora, Rodentia, Chiroptera, Apes, and Man, in the Discoplacentalia. So far as I have been able to examine the literature of the subject, no description of the dissection of a gravid uterus of a Lemur containing a disk-shaped placenta has been put on record. Indeed, until M. ALPHONSE MILNE-EDWARDS published his brief Memoirs on their placentation, no gravid uterus of a Lemur appears to have been examined. Because the Lemurs corresponded to the Apes in the opposability of the thumb and great toe, in the presence of incisor, canine, premolar, and molar teeth, and in the pectoral position of at least two of the mammæ, and to the Insectivora in the pointed tubercles on the crowns of the molar teeth, it has apparently been assumed that they must also correspond with the Apes and Insectivora in the possession of a disk-shaped placenta. The observations of M. ALPHONSE MILNE-EDWARDS have, however, clearly proved that the placenta in the Lemurs is not disk-shaped; and though he applied to it the name bell-shaped, he yet concluded that it had affinities to the zonary placenta of the Carnivora.

From the description which I have given in this Memoir of the arrangement and structure of the maternal and fœtal parts of the placenta in the several genera examined, it will I think be at once admitted that not only is the placenta in the Lemurs not discoidal, but that it cannot be regarded as a modification of the zonary form of placenta.

Both in form and structure the placenta in the Lemurs is without doubt a diffused placenta. To make this important conclusion clearer, I shall summarize the facts which prove this to be the character of the placentation.

a. By gentle traction the ridges and villi of the chorion can be drawn out of the sulci and crypts of the uterine mucosa so that the fœtal and maternal parts of the placenta can be readily and completely separated from each other, as can be done in the diffused placenta of the Pig, Mare, or Cetacean, but as cannot be done either in the discoid placenta or in the zonary placenta of the Carnivora.

b. The chorion is prolonged from the tip of one cornu, through the corpus uteri, to the tip of the opposite horn, as in the uniparous Mare and Cetacean, and is not, as in the uniparous Seal, limited to the side of the uterus in which the fœtus is developed.

c. That the villi are not uniformly distributed over the entire surface of the chorion in the Lemurs is no argument against the diffused character of the placenta; for in none of the other specimens of the diffused placenta which I have examined (viz. the Pig, Mare, *Orca*, Narwhal, *Balænoptera*, *Manis*, and Dromedary) have I seen the whole surface of the chorion covered by villi. In the genera of Lemurs which I have here described, and in the additional genera *Lepilemur*, *Hapalemur*, and *Cheirogaleus* described by M. A. MILNE-EDWARDS, a considerable surface free from villi, corresponding to the presenting part of the fœtus, lay opposite the os uteri. In the Mare, *Orca*, and the Narwhal I have also seen a smooth surface of chorion bare of villi in this locality, which in the Narwhal measured 6 inches in one direction by 4 in another; in *Orca* and in the Mare the bare patch was smaller in size. In my specimens of *Lemur rufipes* a bare surface was also found on the poles of the chorion situated in the uterine cornua; but this is also a not unfrequent character in the diffused placenta, for I have seen it in *Orca*[*], the Mare, and the Narwhal[†]. In the Narwhal the chorion occupying the non-gravid horn was bare of villi for about 5 inches from the pole, and even for a greater distance the villi were irregularly scattered, so that well-defined smooth patches could be traced as far as 10 or 12 inches from the pole; whilst the end of the chorion in the gravid horn had smooth bands radiating for about 1 inch from the pole. In the pluriparous Pig, as was known to VON BAER, the poles of the chorion are free from villi; and in one animal which I examined I found a smooth non-villous surface extending for nearly 3 inches from each pole. The smaller bare patches in the Lemurs situated amidst the villous surface are also not without their homologues in other forms of the diffused placenta. In the Narwhal smooth spots, varying in diameter from $\frac{1}{10}$ to $\frac{2}{10}$ inch, and surrounded by villous tufts, were occasionally situated on the villous surface of the chorion, and these spots were in apposition with smooth surfaces of the mucosa free from crypts. In the Pig numerous star-like spots, varying from $\frac{1}{5}$ to $\frac{1}{20}$ inch in diameter, were scattered over the surface of the chorion, and these spots were in apposition with smooth surfaces of the mucosa free from crypts. In the Mare narrow smooth bands of chorion were in apposition with smooth ridges on the uterine mucosa. In *Balænoptera* and the Dromedary I have also seen non-villous surfaces on the chorion, but the want of the uterus prevented me from localizing them in their relations to the mucosa. In *Manis*, as Dr. SHARPEY pointed out, a band free from villi ran longitudinally along the concavity of the chorion, and there was a corresponding bald space on the surface of the uterine mucosa.

d. The shortness of the villi and the shallowness of the crypts situated in the mucosa for their reception are characters common to all the examples of diffused placenta which I have examined. It is owing to this arrangement that the ready separation of the fœtal placenta from the maternal can be effected, as the hand and fingers can be drawn out of a glove.

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[*] I have given a detailed description of the placentation of *Orca gladiator* in Trans. Roy. Soc. Edinb. 1871.

[†] An account of the placentation of the Narwhal is given in Proc. Roy. Soc. Edinb. Feb. 1876.

e. The form and arrangement of the crypts and the distribution of the blood-vessels in their walls are so like what I have seen in *Orca* and in the Narwhal, that it was difficult, when the preparations were placed side by side, to distinguish the one from the other.

f. In the Lemurs the glands did not open into the crypts, but on the surface of the depressed smooth areas of the mucosa surrounded by the crypts; in the Pig, the Mare, and occasionally in the Narwhal the glands also did not open into the crypts, but on intermediate smooth surfaces of the mucosa,—the peculiarity in the Lemurs being that the mouths of so many glands were concentrated in one area; whilst in the Pig and Narwhal, so far as I have seen, only a single gland opened in each smooth area, and in the Mare the mouths of the glands opened at intervals on the ridges which separated the crypt areas from each other. The placenta in the Lemurs, therefore, corroborates the conclusions which have been drawn by Professor ERCOLANI, of Bologna, and myself, from the study of various forms of placenta, that the crypts which receive the villi are not produced by a dilatation of the glands, but are new structures arising during pregnancy from a hypertrophy and folding of the interglandular part of the mucous membrane*.

In further illustration of the arrangement of the utricular glands in the Lemurs, I may relate some observations which I made some months ago on the non-gravid uterine mucosa in the Slow Lemur (*Nycticebus tardigradus*). The mucosa in each cornu was elevated into six distinct longitudinal folds. It was as thick as the muscular coat, and covered by a well-defined layer of columnar epithelium. In the deeper part of the mucosa the glands were seen to branch repeatedly, and the number of tubes was considerable. In vertical sections through the membrane these tubes were cut across, some transversely, others obliquely or longitudinally. From these branched tubes comparatively few gland-ducts proceeded, which ran very obliquely to open on the free surface of the mucosa; so that the paucity of the tubular glands near the free surface of the mucosa, as compared with the deeper part of that membrane, was in conformity with what I saw in the gravid uterus of *Lemur rufipes*. In the uteri of the Pig, Mare, *Orca*, and the Narwhal a gland stem or duct is also formed by the junction of several branches.

In the Lemurs, as in other placental mammals, the crypts are without doubt secreting organs. The columnar epithelium which lines them has the characters of a secreting epithelium, and the compact subepithelial capillary plexus supplies an abundance of blood from which the secretion may be formed†. The concentration of the mouths of the utricular glands in special areas dissociates their secretion from that of the crypts. The villi which fit into the crypts are the parts of the chorion which absorb their secretion; whilst the smooth, non-villous surfaces of the chorion opposite the smooth areas on the mucosa are engaged in the absorption of the secretion of the glands.

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* The evidence on which this conclusion is based is supplied by Prof. ERCOLANI in a series of Memoirs which have appeared in the 'Mem. dell' Accad. delle Scienze di Bologna' from 1868 to 1873, and by myself in my Lectures on the Comparative Anatomy of the Placenta, before the Royal College of Surgeons of England, June 1875, 1st series, published at Edinburgh, 1876.

† The argument in support of the secreting function of the uterine crypts formed during the development of the placenta is stated in my lectures before the Royal College of Surgeons of England, above referred to.

As the placenta in the Lemurs has the arrangement and structure of a diffused placenta, it is presumably as non-deciduate as that of the other animals which possess the same form of placenta; for in it, as in them, the fœtal placenta can be separated from the maternal without carrying away a portion of the uterine mucous membrane. The demonstration, therefore, of the diffused and non-deciduate nature of the placenta in the Lemurs has an important bearing on the classification of these mammals. As it may be desirable to say a few words on this matter, I shall commence by a brief review of the opinions expressed by various zoologists of the position of the Lemurs in the class Mammalia.

As is well known, LINNÆUS constructed the order *Primates* to include Man, Apes, Lemurs, and Bats. BODDAERT, in 1785, proposed the term *Quadrimana* for the Apes and Lemurs, as expressing the four-handed function of their limbs. BLUMENBACH, in 1795, and CUVIER, shortly afterwards, separated the Apes and Lemurs from Man and the Bats, and made for them the distinct order *Quadrumana*; and this arrangement, with some variations in the mode of subdivision of the order, has been adopted by Messrs. ST.-HILAIRE, WATERHOUSE, H. MILNE-EDWARDS, OWEN, VROLIK, VAN DER HOEVEN, and GIEBEL. DE BLAINVILLE preferred to retain the order *Primates*, in which he included the Apes and Lemurs; and this arrangement, with some variations in the mode of subdivision of the order, has also been adopted by Messrs. J. E. GRAY, ST. GEORGE MIVART, and HUXLEY.

Several zoologists have, however, regarded the structural differences between the Apes and Lemurs as so important that they could not be included in the same order. In 1830, WAGLER proposed that the Apes should form the order *Simiæ*, and the Lemurs the order *Lemures*. GRATIOLET also separated the Lemurs from the Apes, and placed them at the head of the Bats and *Insectivora*; PAUL GERVAIS is also of opinion that they should form a distinct order. M. ALPHONSE MILNE-EDWARDS, in his memoirs already quoted, adduces various reasons against including the Apes and Lemurs in the same order, and proposes the order *Lemuria*, which he considers to have closer affinities with the *Carnivora* than with the Apes, Bats, and Insectivores. HAECKEL, VICTOR CARUS, and CLAUS have also regarded the structural characters of the Lemurs as possessing an ordinal value, and adopting a term applied to these animals by BRISSON, so far back as 1756, have constructed for them the order *Prosimii* or Half-Apes. HAECKEL and CARUS regard the Lemurs as the oldest group of disco-placental mammals. By all these naturalists, with the exception of M. ALPHONSE MILNE-EDWARDS, whether they place these animals in a distinct order or not, the Lemurs are regarded as having closer affinities to the Apes, *Insectivora*, and Bats than to any other mammals.

The demonstration of a diffused, non-deciduate placenta in the Lemurs introduces a new structural element into the consideration of the position they ought to occupy in the class Mammalia. If, as has been done by several eminent zoologists, the form and structure of the placenta are to be taken as the chief guides in the classification of the Mammalia, then the Lemurs can no longer be associated with those orders in which a discoid, deciduate placenta occurs. Not only in the form and structure of the placenta, but in the large size of the sac of the allantois, the Lemurs approach more closely to the *Perissodactyla*, *Suina*, and *Cetacea* than to any of the other orders of mammals, and ought, therefore, to be grouped along with them, if the placenta is to be taken as the dominant character for purposes of classification. The question, therefore, naturally arises whether the placental characters are of such primary importance as to outweigh, in framing a system of classification, those furnished by the other organic systems. The same question also arose in the course of an investigation into the placentation of the Sloths*, when I demonstrated that in *Cholopus* the placenta was multilobate, discoid, and deciduate, whilst Dr. SHARPEY had previously shown that in *Manis* the placenta was diffused and non-deciduate; so that if the placenta be taken as the basis of classification *Manis* and *Cholopus* could no longer be regarded as members of the same order *Edentata*. In the case of the Lemurs it will, I think, be considered by most zoologists that the characters of the teeth, the general configuration of the skeleton, the unguiculate digits, the hand-like form of the distal part of the extremities, the presence of a calcarine fissure in the cerebrum, and the pectoral position of at least two of the mammæ are characters which indicate that the Lemurs have much closer affinities with those mammalian orders with which it has been customary to associate them, than with the *Perissodactyla*, *Suina*, and *Cetacea*. Collectively these characters ought, I think, to be regarded as more valuable indications of structural affinity, than should the presence in the Lemurs of a non-deciduate, diffused placenta with a large allantois be regarded as indicative of structural dissimilarity from the Apes and *Insectivora*, though the placenta in the latter is deciduate and discoid and the allantois aborted.

But though I am of opinion that the general affinities of the Lemurs are such as to lead one to retain them in association with the Apes and *Insectivora*, there can, I think, be no question that the diffused and non-deciduate nature of their placenta, with the large allantoic sac, are distinctive characters of so much importance that they cannot be classed in either of those orders, but have themselves an ordinal value. Hence I agree with those zoologists who separate the Lemurs from the Apes; and to the distinctive characters derived from the teeth, skeleton, &c., advanced by previous writers, I would add those to be drawn from the placenta and the fœtal membranes.

In conclusion, it may not be without interest to consider how far the determination of the non-deciduate, diffused character of the placentation in the Lemurs affects the theory advanced by Professor HAECKEL†, that the Half-Apes (*Prosimiæ*) were the primary form out of which the several orders of deciduous placental mammals had originated.

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* Transactions of the Royal Society of Edinburgh, 1873.

† 'Natürliche Schöpfungsgeschichte.'

In constructing his pedigree of the Mammalia, HAECKEL, though admitting the difficulty of solving the question, is inclined to think that the placental mammals had at once diverged into two completely distinct groups, a Non-deciduate and a Deciduate. Out of the Non-deciduata, he says, had proceeded the *Ungulata* and *Cetacea*, with their diffused or cotyledonary forms of placenta; out of the Deciduata had arisen the *Insectivora*, *Carnivora*, *Chiroptera*, *Rodentia*, *Hyracoidea*, *Proboscidea*, Lemurs, Apes, and Man, with a zonary or discoid form of placenta; whilst the primæval form common to all the Deciduata was the group of Half-Apes, or *Prosimiæ*, of which the Lemurs of the present day are the descendants and representatives.

The principle which guided HAECKEL in framing his pedigree of the Mammalia rendered it necessary for him to assume that the Lemurs possessed a deciduate placenta, so that they might serve as the primary group of origin of the deciduate mammals. But I have just shown that in these animals the placenta is diffused and non-deciduate, so that the Lemurs must be transferred to the Non-deciduata, and, on the hypothesis advocated by HAECKEL of an independent origin of the Deciduata and Non-deciduata, they can no longer be regarded as the root form of the deciduate mammals.

It appears to me, however, that the conditions of the theory of descent may, so far as it is based on a consideration of placental characters, be more satisfactorily provided for by assuming that the deciduate placenta had been evolved from the non-deciduate, rather than that an abrupt divergence into two distinct placental groups had occurred*. No one, I suppose, would doubt that the diffused placenta has the most simple mode of structure, and that the distribution of the villi over the surface of the chorion presents a close approximation to the primary embryonic arrangement; whilst the discoid placenta exhibits the greatest departure from the diffused villous chorion of the early embryo. Not only is the placenta in the discoid form concentrated in a limited area, but its internal structure is much more complicated; for the diminution in the relative proportion of the surface of the chorion, subserving the function of a placenta, has rendered necessary a greater degree of complexity in the form of the villi and in the foldings of the uterine mucosa throughout the placental area. It seems to me, therefore, to be more in accordance with a theory of descent that the complex form of placenta should be regarded as having been evolved out of the simple, than that each should have arisen independently, as is assumed by HAECKEL, out of a non-placental subclass of Mammalia.

I have elsewhere recorded† observations on the structure of the placenta which show that the line of demarcation between the Non-deciduata and Deciduata is not so abrupt as has usually been supposed, but is graded over by an intermediate arrangement—the passage from the diffused placenta, in which no maternal tissue deciduates during parturition, to those deciduate placentæ in which both the epithelial and subepithelial vascular tissue of the uterine mucosa are shed being effected through the cotyledonary placenta, in which the epithelial lining of the maternal cotyledons separates along with the fœtal villi. I have also shown* that amongst the deciduate placentæ, in the different genera and orders, considerable variations occur in the relative proportion both of the epithelial and subepithelial vascular tissue of the placental area shed during parturition.

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* In the last of my Lectures on the Comparative Anatomy of the Placenta, delivered at the Royal College of Surgeons, June 1876, and printed in the Journal of Anatomy and Physiology, Oct. 1876, I have discussed at much greater length the structure of the placenta in relation to the theory of evolution.

† Proceedings of the Royal Society of Edinburgh, 1875.

On the hypothesis which I have just advanced, that the more complex forms of placenta may have been evolved out of the more simple, the possibility that the Lemurs, notwithstanding the non-deciduate and diffused character of their placentation, may have been the stock from which the deciduate mammals had been derived does not present so many difficulties as are involved in the hypothesis put forward by Professor Haeckel.

Explanation of Plates 49, 50, 51.

For the series of coloured drawings in illustration of this memoir, which have been drawn with great care under my superintendence, I am much indebted to my former assistant, Mr. Alfred H. Young, M.B.

Fig. 1. Posterior surface of the gravid uterus of *Propithecus diadema.* Natural size.

Fig. 2. Posterior surface of the gravid uterus of *Lemur rufipes.* Specimen A. Natural size. *f*, fecundated, and *nf* non-fecundated cornu; *o o*, ovaries.

Fig. 3. Outer surface of chorion from the gravid uterus of *Lemur rufipes.* Specimen A. Natural size.

Fig. 4. Outer surface of chorion of *Lemur rufipes.* Specimen B. Natural size. *f*, the pole in the fecundated cornu of the uterus; *nf*, the pole in the non-fecundated cornu; *b*, the bare surface opposite the os uteri.

Fig. 5. Ovum of *Lemur rufipes.* Specimen C. Natural size. The chorion in the fecundated cornu has been cut through by a longitudinal incision, and the sac of the allantois opened into. V, the villous surface of the chorion at one pole; *am*, the amnion, containing the fœtus, seen through the layer of allantois which covers it; *al*, the line of reflection of the allantois from the outer surface of the amnion to the inner surface of the chorion; *uv*, vessels of the umbilical cord passing to the chorion; *nf*, the pole in the non-fecundated cornu.

Fig. 6. The inner surface of the gravid uterus of *Propithecus diadema* after the removal of the fœtus and its membranes. *f*, the fecundated cornu, the mucosa of which displays the sinuous folds and the depressed smooth areas described in the text; *nf*, the non-fecundated cornu; *os*, the fold of mucosa which marks the os uteri; V, the vagina. Natural size.

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* Memoir on the Placentation of the Seals, in Transactions of the Royal Society of Edinburgh, 1875.

Fig. 7. Free surface of a small portion of the uterine mucosa of *Propithecus diadema.* × 2 diameters. The convoluted folds of the mucous membrane with their crypts are represented, and amidst these folds five smooth depressed areas, in which the mouths of the utricular glands open, may be seen.

Fig. 8. Anterior surface of the gravid uterus of *Indris brevicaudatus* in an early stage of pregnancy. Natural size. *f*, fecundated, *nf* non-fecundated cornu. *o o*, ovaries; *l*, round ligament; V, vagina.

Fig. 9. Surface view of one of the smooth depressed areas on the uterine mucosa of *Lemur rufipes.* × 50 diameters. In the smooth area may be seen the open mouths of a number of glands which converge to the area from beneath the surrounding crypts. The great vascularity of the walls of the crypts is shown, but at the right side of the figure the injection has not penetrated into the capillary plexus. If this drawing be compared with the free surface of the uterine mucosa of the gravid Pig, as figured in my paper in the 'Journal of Anatomy and Physiology,' October 1875, a close correspondence will be seen in the arrangement and vascularity of the crypts; but whilst the smooth depressed spot in the Pig has only one gland opening in it, that in the Lemur has between twenty and thirty. The specimen satisfactorily shows the independence of the glands and the crypts; for although the glands are subjacent to the crypts, they do not open into them.

Fig. 10. Vertical section through two convoluted folds and an intermediate sulcus of the uterine mucous membrane of *Propithecus diadema.* *a*, the vascular crypt layer of the mucosa; *b*, the subjacent glandular layer; *c*, the muscular coat. If this drawing be compared with a similar vertical section through the uterine mucosa of *Orca gladiator*, which I have figured in the Transactions of the Royal Society of Edinburgh, vol. xxvi. plate xviii. fig. 12, a remarkable resemblance in the form and vascularity of the crypts will be seen; in *Orca*, however, the glandular layer is thicker than in *Propithecus*. *f f*, two folds vertically divided; *s*, intervening sulcus. Both the sulcus and the folds are thickly pitted with crypts. × 50 diameters.

Fig. 11. A more highly magnified view of portions of the walls of two crypts, to show the relation of the columnar epithelial lining of the crypts to the capillary plexus in the wall. A, a crypt vertically divided; B, a crypt cut across obliquely.

Fig. 12. A portion of the chorion of *Propithecus diadema*, magnified, to show the subdivision into villi of the ridges which traverse its free surface.

ADDENDUM.—July 15th, 1876.

A few days ago the Library of the University of Edinburgh received the recently published parts of the great work 'Histoire physique, naturelle et politique de Madagascar,' publiée par ALFRED GRANDIDIER, Paris, Imprimerie Nationale, 1875. The parts published are vol. ix. tome iv. atlas 1, and vol. vi. tome i. texte 1, première partie, in which the description and illustration of the Natural History of the Mammals of Madagascar is commenced by MM. ALPHONSE MILNE-EDWARDS and ALFRED GRANDIDIER. From a note in the 'Comptes Rendus' of 20th December, 1875, p. 1280, which I did not see until after this Memoir had been communicated to the Royal Society, it would appear that these volumes were published at the close of last year.

The volume of text contains a description of the osteology and myology of the family *Indrisinæ* of the order of Lemurs. The volume of the atlas contains 122 beautiful lithographic and photographic plates in illustration of the external form and colour and the internal anatomy of this family of Lemurs. Plates 113 to 121 inclusive are devoted to figures of the gravid uterus and its contents in *Propithecus diadema*, *Edwardsii*, and *Verreauxii*, *Avahis laniger*, and *Indris brevicaudatus*; but no description of these figures has been published either with the atlas or in the volume of text. The generally villous surface of the chorion is shown in these figures, and in *Propithecus diadema* smooth spots are scattered amidst the villi; but no similar spots are represented on the chorion of the other species, though *P. Edwardsii*, *P. Verreauxii*, and apparently *Indris brevicaudatus* have a smooth chorion opposite the os uteri. In none of the figures is the presence of a rudimentary horn to the chorion extending into the non-fecundated uterine cornu represented. In *P. diadema* and *I. brevicaudatus* the uterine mucosa is seen to be raised into minute folds, and in *P. diadema* the presence of depressed smooth areas on the mucosa is shown. Beyond figuring a capillary plexus in the fœtal villi and uterine mucous membrane, no representation of the minute structure of the placenta has been given, and no notice is taken of the uterine glands and of their relations to the depressed areas in the mucosa. The illustrations, therefore, are incomplete in some interesting and important particulars. The amnion, allantois, and a small pedunculated sac, which looks like the umbilical vesicle, are, however, beautifully figured.

XXIII. *Experiments on the Friction between Water and Air. By Dr.* VIKTOR VON LANG, *Professor of Physics in the University of Vienna. Communicated by* N. S. MASKELYNE, *M.A., F.R.S., Professor of Mineralogy in the University of Oxford.*

Received February 28,—Read April 6, 1876.

WE have only a few notices on the subject of the friction between air and water, and these few contradict each other. J. B. VENTURI[*] states that the air put into motion by a jet of water moves light bodies. G. MAGNUS[†] opposes this, as he finds that a flame brought near to a vertical jet of water indicates no motion of the surrounding air. The following experiments show, however, that great friction does really take place between water and air, so great as scarcely to differ from total adhesion.

But it is very much to be doubted whether VENTURI was acquainted with this pure friction between water and air, as he does not say any thing about the constitution of his jets. It must be remembered that VENTURI experimented long before SAVART, who was the first to distinguish the two parts of a vertical jet of water, the continuous part and the other broken up into drops. The above-mentioned phenomenon can be demonstrated only on the first part, though the discontinuous part of the jet moves the surrounding air too, and with much more energy. But in this case MAGNUS was quite right when he attributed the motion of the air to other causes.

Description of the Apparatus (Plate 52. figs. 1 & 2).

After what I have just said it is clear that I had to begin my experiments with producing a continuous vein of water. MAGNUS gives the necessary directions; but he lets the jet flow immediately from the reservoir, whilst I wished to use directly the conduit by which the city of Vienna has recently been supplied with water from the mountains. There is no doubt that in this way many inconveniences would be avoided, that make the method of MAGNUS and his predecessor SAVART tolerably troublesome. After a good many failures I succeeded at last, principally by inserting a caoutchouc tube between the water-tap and the delivering tube A.

The latter tube is of glass, 8 centims. long, outer radius 0·72 centim., inner radius 0·54 centim. It is not plane at the lower end, but irregularly indented.

The whole delivering apparatus must be set up in a very solid way; even the slightest shake is sufficient to break up the continuous jet into single drops; besides one must have the means of adjusting the delivering tube to a vertical position in order to avoid a displacement of the axis of the jet when the quantity of the water augments or diminishes. Both purposes may be attained in the following way:—

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[*] Recherches expérimentales sur le principe de communication latérale dans les fluides, appliqué à l'explication de différents phénomènes hydrauliques. Paris, 1797.

[†] "Über die Bewegung der Flüssigkeiten," POGGENDORFF's Annalen der Physik und Chemie, Band lxxx. (1850).

A wooden beam (B) is horizontally attached to the two walls forming the sides of the recess of a window. On it is fixed a brass plate (C) by means of two pulling and two pushing screws. The plate supports a vertical tube (D) of brass, 4 centims. long, and with an outer radius of 1·1 centim.; and this tube holds the delivering tube, which is cemented into it air-tight, and of course stands out at both ends.

By means of the above-mentioned four screws the delivering tube can be rendered vertical, remaining at the time totally independent of the vibrations of the floor.

The caoutchouc tube E that unites the delivering tube with the water-tap F below it is about one metre long and 0·3 centim. thick. The distance of the two ends of the caoutchouc tube is in vertical direction 30 centims., in horizontal direction 40 centims.; strings fastened to the ceiling hold up the tube.

By these arrangements it was possible to have continuous veins (W) of water of different lengths. The maximum lengths, however, could not be determined, the jet meeting, 130 centims. below the orifice, a board that was also fixed to the walls. If the quantity of water was so regulated by the tap F that the jet remained continuous till it reached the surface of the water in a vessel put under it, nothing was to be heard of the movement of the water, and the vein looked like a glass rod.

This regularity was of course disturbed in the most unpleasant way as often as the water-pipes were made use of in neighbouring places. A pressure-gauge inserted into the conduit indicated, however, when the normal state was restored. This normal pressure of the water at the place of observation is four atmospheres.

I have to describe now the special contrivances for the demonstration of the friction between the air and the continuous vein of water. There is first of all a crosspiece (G) made of glass tubes with an outer radius of 1·1 centim. One of the four arms of this crosspiece has a length of 36 centims., the other three a length of 7 centims. The long arm is to be united air-tight by a caoutchouc tube with the lower end of the brass tube D, both tubes having on this account the same outer radius. In this position of the crosspiece two arms of it stand horizontally. An open manometer is fastened to one of these arms by means of a caoutchouc connexion; the other arm leads to the "measuring tube" I, with which it is connected air-tight by a short caoutchouc tube. This tube I serves to measure the motion of the air caused by its friction on the jet of water in the "aspirating tube" K, the section of which does not very much exceed the section of the water vein. The aspirating tube is held up by the fourth arm of the crosspiece, with which it is united air-tight by a caoutchouc mouthpiece (L), such as is used for nursing children. The upper end of this tube was always brought to the height of the horizontal axis of the crosspiece, 35 centims. below the delivering orifice; the lower end was generally widened like a funnel to avoid disturbances by adhering drops. For the purpose of adjusting the aspirating tube so as to make its axis coincide with the axis of the water vein, I placed a heavy stand (M) with three movable arms on the above-mentioned board. Each of these arms ends in a ring with three screws, to hold a tube in the middle. The uppermost ring (N) serves only for securing the crosspiece, the longest arm of which is held up by it. As to the rest this arm does not differ from similar contrivances for chemical purposes. For the other two rings (O, O′), however, that have to hold the aspirating tube, one must have two horizontal motions perpendicular to each other and worked by screws. This is done in the following manner:—The sliding piece P, that belongs to ring O, bears a four-sided horizontal hole, into which fits a four-sided brass bar Q, the posterior end of which is worked into a screw. The nut R to this screw is held by a fork S fixed to the sliding piece, and the turning of this nut makes the bar move forward and backward. On one side of this bar is fixed the end of a strong spring T that bears in front the ring O. The spring presses against a screw U that goes horizontally through the four-sided bar, and that brings the ring to move nearly in a straight line from right to left.

About the measuring tube I have still to say that it forms a knee with two unequal arms. The shorter arm has also an outer radius of 1·1 centim., and is united, as I mentioned before, with one of the horizontal arms of the crosspiece by a short caoutchouc tube. The other arm of the knee is generally directed downward, and forms the proper measuring tube; its radius was taken of various sizes, exact measurements requiring a larger radius; it was then necessary to make the measuring tube of two pieces, that were united air-tight by cork and sealing-wax.

The motion of the air caused by the aspiration of the jet of water can now easily be rendered visible by means of soap-laminæ. If the open end of the measuring tube is immersed in a solution of soap, and if we remove this solution slowly, it leaves behind a lamina that immediately begins to follow the motion of the air in the aspirating tube. The whole measuring tube being wetted inside, such laminæ travel even through the horizontal part of the tube, till they burst at the mouth of the aspirating tube. One can also get a nearly infinite number of laminæ to ascend one after the other at the same time; and in this case the laminæ keep still better, as the velocity of the whole movement decreases with their number.

If we want to measure* the volume of the aspirated air, we shall employ a single lamina, and fix on the measuring tube a paper scale, by which we can determine the course of the lamina in one second. This quantity and the inner radius of the tube give the aspirated volume most easily.

There is still another way to study the motion of air caused by a jet of water by means of the described apparatus. In this case the measuring tube is replaced by one of metal. The open end of it is directed downward, and the flame of a turpentine-lamp is held in it. The intense smoke of such a flame reveals immediately vehement motion where all seems to be calm. The smoke ascends at the sides of the crosspiece, and descends near the jet of water. There is, of course, an intermediate zone without vertical motion; but in this zone a very violent rotation takes place around a horizontal axis perpendicular to the radius. This is shown by larger particles of soot that come by chance into this zone.

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* This method of measuring volumes of gases was already employed by Dr. T. Exner in his "Researches on the Diffusion of Gases through Liquid Laminæ," Sitzungsberichte der Wiener Akademie, Band lxx. (1874).

As to the motion of the air in the aspirating tube, the smoke is not dense enough to be seen in it when the radius of the tube is very small; but one sees that the smoke, in leaving the tube, continues to surround the jet for some time. This shows that the particles of air flow through the tube in parallel lines very regularly.

The last phenomenon does not take place any more when the radius of the aspirating tube becomes larger. In this case one can also see the smoke, and observe by it that the motion of the air is now very irregular, although no ascending movement can be detected.

Determination of the Form of the Water-jet.

The quantity of the aspirated air varies of course with the radius of the jet and with the velocity of the water on the surface of it. For finding this latter velocity there was nothing to be done but to suppose the velocity constant for the whole section of the jet. The velocity may then be calculated easily from the radius of the jet and from the volume of water discharged in one second. These two quantities depend on one another for each section of the jet. Having made corresponding measurements of them in different places of the jet, we may afterwards compute the radius only from the quantity of water discharged.

The measuring of the radius of the jet was effected by means of a kathetometer placed at a distance of 2 metres from the jet. The telescope bears an ocular micrometer, and its magnifying power is such that the distance of 1 centim. needs 6·80 turns of the micrometer-screw. I have to add that the quantity of water per second was found by weighing the quantity discharged in 5 seconds.

It would be sufficient for what follows to know the form of the jet from 35 centims. below the orifice. But it seems to me that for other problems it might perhaps be of interest to know the form of a jet of water beyond that limit also, and therefore I shall give my complete observations here.

In the following Table (p. 593) z denotes the vertical distance from the orifice, W the quantity of water discharged in one second, and r the radius of the jet at the place given by z. The distance z is measured in centimetres, W in grammes, and r in turns of the micrometer-screw. The numbers given for W and r are means from two to ten observations.

The column headed r' gives the values of r calculated by the following formulæ:—

$z=35 \qquad r=1{\cdot}1860+0{\cdot}045202\ \mathrm{W}.$

$45 \qquad 1{\cdot}1503+0{\cdot}041941\ \mathrm{W}.$

$55 \qquad 1{\cdot}0566+0{\cdot}041354\ \mathrm{W}.$

$65 \qquad 1{\cdot}0606+0{\cdot}036555\ \mathrm{W}.$

$75 \qquad 0{\cdot}7064+0{\cdot}049137\ \mathrm{W}.$

z.	W.	r.	r′.	r−r′.
5	2·2	1·29		
	4·0	1·56		
	8·0	2·24		
	12·0	2·72		
	15·8	2·98		
	18·5	3·24		
	23·1	3·67		
	29·5	4·07		
15	2·5	0·88		
	4·7	1·03		
	9·0	1·76		
	13·5	2·13		
	23·0	2·60		
	26·6	2·99		
	33·8	3·40		
25	5·4	1·20		
	9·4	1·52		
	13·0	1·80		
	19·0	2·13		
	24·0	2·45		
	29·7	2·75		
	33·5	2·95		
35	9·0	1·29		
	11·5	1·60		
	13·8	1·68		
	18·2	2·02	2·009	+0·011
	25·4	2·31	2·334	−0·024
	31·0	2·60	2·587	+0·013
45	8·1	1·25		
	11·2	1·50		
	13·8	1·68		
	18·0	1·85	1·905	−0·055
	24·2	2·25	2·165	+0·085
	27·4	2·30	2·299	−0·001
	34·8	2·58	2·610	−0·030
55	10·4	1·27		
	11·9	1·36		
	14·2	1·51		
	16·9	1·80	1·755	+0·045
	20·7	1·92	1·921	−0·001
	25·6	2·09	2·115	−0·025
	32·4	2·37	2·396	−0·026
65	12·9	1·36		
	14·7	1·56		
	18·3	1·73	1·729	+0·001
	23·8	1·93	1·931	−0·001
	28·6	2·11	2·106	+0·004
	36·2	2·38	2·384	−0·004
75	12·4	1·27		
	16·2	1·51	1·502	+0·008
	21·5	1·80	1·763	+0·037
	28·8	2·01	2·097	−0·087
	33·2	2·38	2·338	+0·044

The constants of these formulæ have been determined by the method of least squares from the corresponding values of r found by direct observation. The last formulæ give for $W=20$ and $W=30$ the following numbers for r:—

W.	z.	r.	r'.	$r-r'$.
20	35	2·090	2·085	+0·005
	45	1·989	1·957	+0·032
	55	1·884	1·865	+0·019
	65	1·791	1·795	−0·004
	75	1·689	1·741	−0·052
30	35	2·542	2·567	−0·025
	45	2·408	2·404	+0·004
	55	2·297	2·287	+0·010
	65	2·157	2·198	−0·041
	75	2·181	2·129	+0·052

The calculated values of r denoted by r' were found by the formulæ

$$W=20 \qquad r=0{\cdot}9976+6{\cdot}4342\,\frac{1}{\sqrt{z}},$$

$$30 \qquad 1{\cdot}1819+8{\cdot}1973\,\frac{1}{\sqrt{z}},$$

the constants of which were also determined by the method of least squares from the foregoing values of r. The calculated numbers agree in this case too with the observed ones, as well as is necessary for the present purpose. From the last two formulæ the following equation,

$$r=0{\cdot}6290+0{\cdot}01843\,W+(2{\cdot}9080+0{\cdot}17631\,W)\,\frac{1}{\sqrt{z}},$$

was finally deduced, which gives the radius of the jet for any height and quantity of water. Expressing the turns of the micrometer-screw by centimetres, we have, in accordance with the value given above for these turns,

$$r=0{\cdot}09246+0{\cdot}002709\,W+(0{\cdot}42748+0{\cdot}025918\,W)\,\frac{1}{\sqrt{z}}.$$

Determination of the Volume of the Aspirated Air.

I have already explained the method used for measuring the volume of the aspirated air. However, the question arises whether, in following this method, the volume measured by the motion of a soap-lamina is really equal to the volume that is aspirated when the measuring tube is quite open. First of all the weight of the lamina might be of influence, acting in a sense contrary to the movement of the air. But the experiment can easily be arranged in such a way that the weight of the lamina favours the air's motion: one has only to put in the measuring tube with its open end upward; the soap-laminæ cannot now be produced directly, but a large cylinder must be put first of all into the solution of soap, and afterwards the lamina must be transferred from this cylinder to the measuring tube. This procedure can also be of use sometimes when the measuring tube is directed downward.

It was found by such experiments that the weight of the lamina is of no appreciable influence, as both positions of the measuring tube gave the same numbers for the volume of the aspirated air under similar circumstances. The downward position of the measuring tube was therefore constantly adopted in the following experiments, this position being the more convenient.

The radius of the measuring tube, however, is of great importance, and it will be seen by using tubes of different radii that the larger tubes give a greater volume. But this augmentation becomes continually smaller if we proceed with enlarging the measuring tube, and from a certain radius the volume increases no more. At this point we can state that the soap-lamina is without influence on the quantity of aspirated air.

We can make similar observations also on the water-manometer mentioned before. It does not indicate any difference of pressure when during the aspiration the measuring tube remains open; but if we close it by a soap-lamina, the manometer shows a diminution of pressure that becomes the more insensible as the radius of the tube increases.

The radius at which the influence of the section of the measuring tube vanishes depends certainly on the quantity of the aspirated air. A radius of 2·4 centimetres seems to be quite sufficient for my experiments.

The motion of a soap-lamina is of course much slower in larger tubes than in small ones, and can therefore be measured with greater accuracy. The employment of larger measuring tubes is more advantageous on this account also.

The following Table gives the radii of all the measuring tubes that were made use of:—

Meas. tube.	Radius.
I.	1·096 centim.
II.	4·00 centims.
III.	2·42 „
IV.	1·57 centim.
V.	1·13 „
VI.	0·85 „

These tubes may also be employed by couples, placing the second measuring tube in lieu of the manometer. A few experiments which I made in this way will be found among the following measurements.

The first part of these measurements was executed in July 1875 with the aspirating tubes 1–4, the length of which was gradually diminished to find the influence of this dimension. The volume of the air was at the time measured by tube I., the radius of which has not the necessary value, as was found by later experiments. But this circumstance, which is of great influence in regard to the absolute values of the volume of air, may be neglected in the present research. The result of these experiments is that the quantity of the aspirated air approaches to a maximum with the length of the tube. The maximum itself could not be reached exactly, even with the smallest tubes; but this arises certainly from the conical form of the water vein; for within certain limits the volume of the air increases when the vein becomes smaller, the quantity of the water remaining constant. The following Table gives the numbers found by these experiments, the quantity of water discharged being equal to 20 gallons. A is the volume of the aspirated air, *l* the length of the aspirating tube, and R its radius, found by the weight of mercury filling up the tube. The latter two quantities are given in centimetres, and A in cubic centimetres.

Asp. tube.	R.	*l*.	A.
1	0·254	47·2	17·1
		38·2	16·6
		26·0	15·1
		16·0	14·0
2	0 288	47·1	22·3
		37·3	21·8
		26·5	19·1
3	0·383	49·8	28·1
		42·6	25·8
		36·5	22·6
4	0·435	50·5	25·2
		44·0	23·1
		31·7	17·5

The numbers given for A are not directly observed; but at first the mean was taken of all readings for A above and below W=20, and then the required quantity was interpolated between these two means by simple proportion.

For the tubes 1 and 2 the diminution of the volume A is very small, although their length decreases by 10 centimetres. The tubes 3 and 4, on the contrary, seem to be by far too short to give the maximum of A. We may therefore say that an aspirating tube 47 centimetres long, W being equal to 20 gallons, gives the maximum of air only when its radius is below 0·29 centimetre.

The second series of measurements were executed in October of the same year with the aspirating tubes 5–9, all of them 48 centimetres long, and with the measuring tubes II.–VI. The values of A found by these different tubes are given in the following Table. There exists no material difference between the numbers found by the tubes II. and III.; even the coupling of these two tubes did not produce larger volumes. For the following calculations the mean was therefore taken of the values II. and III., and the numbers so found are given in the last column.

Asp. tube.	R.	W.	II.	III.	IV.	V.	VI.	II.+III.	A.
5	0·238	26·0	13·8	14·0	14·1	13·4	12·6	14·0	14·0
6	0·244	25·5	14·7	14·8	14·7	13·8	13·5	……	14·8
7	0·261	20·0	20·5	19·5	18·7	17·8	17·1	……	20·0
		30·0	17·9	17·0	16·6	16·3	15·8	……	17·5
8	0·287	17·0	24·5	25·6	21·3	17·9	17·7	……	25·1
		22·0	24·0	23·8	22·1	19·6	18·4	……	23·9
		30·0	22·5	22·7	20·7	19·7	19·5	……	22·6
9	0·303	20·0	26·0	25·3	21·4	21·7	……	……	25·7
		23·8	25·5	25·2	22·5	21·8	……	26·1	25·6
		30·0	24·7	25·1	22·6	21·9	……	……	24·9

Approximate Theory of the Experiments.

The exact theory of these experiments is rendered still more difficult by the fact that the water-jet has a different radius at different places. But to obtain at least an approximate solution of the problem we will assume a cylindrical form of the jet. In accordance with our smoke-experiments, we assume further that all particles of air flow through the aspirating tube in straight lines parallel to the tube's axis, which we take for the axis of x. The velocity of the air-particles has therefore a finite value u only for this axis, it being zero for any direction perpendicular to this axis.

In consequence of the last statement the pressure must be constant in each section of the aspirating tube. Now we have seen by the manometer that the pressure at the beginning of the tube is the same as at the end, viz. the pressure of the atmosphere; this leads us to suppose that the pressure does not vary at all in the whole length of the tube.

If we consider, further, that the motion of the air in the aspirating tube is a steady one and independent of time, and that no exterior forces exist, the hydrodynamical equations are reduced in the present case to

$$\frac{d^2u}{dy^2}+\frac{d^2u}{dz^2}=0, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

the equation of continuity becoming

$$\frac{d(\mu u)}{dx}=0. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

In this last equation μ denotes the density, which must be constant when the pressure is constant. This equation is therefore satisfied by our suppositions. As regards the equation (1) its integral is

$$u=\mathrm{L}\log q+\mathrm{M}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

q denoting the distance from the axis of x. The constants L and M have to be determined by the motion of the air next to the tube and next to the water-vein. If we assume that no slipping takes place, the air adhering to the glass as well as to the water, we have the corresponding values,

$$\left.\begin{array}{l} q=\mathrm{R},\ u=0, \\ q=r,\ \ u=\mathrm{U}, \end{array}\right\} \quad \ldots\ldots\ldots\ldots \quad (4)$$

U being the velocity of the water at the surface of the jet, given by

$$\mathrm{W}=\pi r^2\mathrm{U}. \quad \ldots\ldots\ldots\ldots \quad (5)$$

By the equations (4) we get

$$u=\frac{\mathrm{W}}{\pi r^2}\,\frac{\log \mathrm{R}-\log q}{\log \mathrm{R}-\log r}; \quad \ldots\ldots\ldots\ldots \quad (6)$$

and in consequence for the volume A of air flowing through the tube per second,

$$\mathrm{A}=\int_r^{\mathrm{R}} u\,2\pi q dq=\mathrm{W}\left[\frac{\mathrm{R}^2-r^2}{2r^2(\log \mathrm{R}-\log r)}-1\right]. \quad \ldots\ldots\ldots \quad (7)$$

In order to compare our observations with this formula, we have still to fix what numerical value we shall assume for the radius of the jet. The simplest way is of course to take for r the mean of its values at the top and at the bottom of the tube; and, indeed, we get in this way a tolerably good result, as is shown by the following comparison of the observed values of A and of the calculated ones designated by A′.

Asp. tube.	r.	A′.	A.	A − A′.
5	0·1582	14·20	14·0	−0·20
6	0·1566	15·56	14·8	−0·76
7	0·1392	20·02	20·0	−0·02
	0·1708	17·22	17·5	+0·28
8	0·1300	24·57	25·1	+0·53
	0·1456	24·77	23·9	−0·87
	0·1708	22·71	22·6	−0·11
9	0·1392	28·06	25·7	−2·36
	0·1512	27·83	25·6	−2·23
	0·1708	26·19	24·9	−1·29

It is not before we come to tube 9 that the differences between the observed and the calculated numbers are greater than the possible errors of observation. But the radius of this tube is already beyond the limit within which our suppositions as to the motion of air hold good.

A still better accord is got by supposing that there is a slipping between the air and the jet of water, and also between the air and the aspirating tube. We get, then, in lieu of the conditions (4) the following ones,

$$\left.\begin{array}{ll} q=\mathrm{R}, & u=-\psi\dfrac{du}{dq}, \\ q=r,\ \ \mathrm{U} & u=-\xi\dfrac{du}{dq}, \end{array}\right\} \quad \ldots\ldots\ldots\ldots \quad (8)$$

where ψ is the coefficient of slipping for the water, and ξ this coefficient for the glass tube. These conditions give for u and L,

$$u=\frac{W}{\pi r^2}\left.\frac{\log R-\log q+\frac{\psi}{R}}{\log R-\log r+\frac{\psi}{R}+\frac{\xi}{r}}\right\}, \quad \ldots \ldots \ldots \ldots \ldots \quad (9)$$

$$L=W\frac{(R^2-r^2)\left(\frac{R^2}{r}+\psi\right)-Rr^2(\log R-\log r)}{Rr^2(\log R-\log r)+Rr\xi+r^2\psi} \quad \ldots \ldots \ldots \ldots \quad (10)$$

The last formula applied to the former observations gives ten linear equations for ξ and ψ, from which one finds, by the method of least squares, $\xi=\psi=0{\cdot}029$. With these numbers we now get the following differences between the observed values of A and the calculated ones:—

	+0·23	−0·26	+0·87	+0·85	+1·69
+0·20	+0·71	−1·86	−1·18	−0·40	

One sees that the accord is of the same degree as before, although the sum of the squares of the errors is now a little smaller, 10·01 against 17·46 as before. The equality of ξ and ψ could easily be explained, as the tube was always wet inside; but the values of ξ and ψ cannot be relied on at all, because they become even negative when the first seven observations only are used for their determination. The real values of ξ and ψ can only be found by taking into account the conical form of the jet.

I have also calculated the first series of observations by aid of the equation (7). The calculated values are of course all too great, as the measuring tube with which the observations were executed was too small; but still one can see that the calculation goes parallel to the observation as long as the limit is not passed within which our theory holds good.

Asp. tube.	l.	r.	A.	A′.	A−A′.
1	47·2	0·1393	17·1	18·5	− 1·4
	38·2	0·1408	16·6	17·8	− 1·2
	26·9	0·1435	15·1	16·9	− 1·8
	16·0	0·1463	14·0	16·1	− 2·1
2	47·1	0·1393	22·3	25·1	− 2·8
	37·3	0·1410	21·8	24·3	− 2·4
	26·5	0·1434	19·1	23·4	− 4·3
3	49·8	0·1389	28·1	45·1	−18·0
	42·6	0·1400	25·8	44·4	−18·6
	36·5	0·1412	22·6	43·9	−21·3
4	50·5	0·1391	25·2	57·2	−32·0
	44·0	0·1398	23·1	56·2	−33·1
	31·7	0·1422	17·5	54·8	−37·3

APPENDIX.

We have seen that even when we put $\xi = \psi = 0$, the differences between calculation and observation are not greater than the errors of observation. We therefore cannot expect essential differences when we employ aspirating tubes of other material. This was also confirmed by experiments made with two brass tubes. In this case it was found a little troublesome to make the jet pass along the axis of the tube, the tube being opaque. The radius of these tubes was determined by means of cylinders fitted carefully into the tubes; their length was again 48 centimetres. In the following Table the values of A are those found by observation, the values A′ those calculated by equation (7).

Asp. tube.	R.	W.	r.	A.	A′.	A−A′.
10	0·228	22·2	0·1461	14·7	13·66	+1·04
		24·9	0·1548	13·6	12·70	+0·90
11	0·270	19·8	0·1386	23·8	21·69	+2·11
		23·7	0·1509	23·2	21·14	+2·06

I have also made a few experiments with other gases. However, no great differences are to be expected in this case either, for the reason stated before, as differences could only arise from different coefficients of slipping. In these experiments the manometer-arm of the crosspiece was used for introducing the gas. In order to get the apparatus totally freed from air, the soap-lamina was alternately aspirated by the jet and driven back again to the mouth of the measuring tube by introduction of new gas. The results obtained are:—

Asp. tube.	W.	r.	A.	A′.	Name of gas.
6	24·3	0·1528	15·2	16·0	Coal-gas.
7	30·0	0·1708	17·0	17·2	,, ,,
8	24·2	0·1525	25·1	24·4	,, ,,
	26·0	0·1461	26·0	24·0	Carbonic acid.

XXIV. *On the Structure and Development of the Skull in the Batrachia.*—Part II.

By William Kitchen Parker, *F.R.S.*

Received October 28,—Read December 16, 1875.

Introductory Remarks.

The first paper offered by me to the Royal Society on the structure of the skull in this group was on that of the Common Frog; this has been followed by a similar piece of work treating of the Salmon's skull, and this latter by another on that of the Pig.

But these are merely an earnest of what I have in hand, and hope in due time to offer to the Society—my one steadfast desire being to master the problem of the skull, and to have the results of my labours published in the 'Philosophical Transactions.'

My former memoir on the Batrachian skull was wrought out under very great difficulties; I was not guideless absolutely, and yet much of my way had to be felt out in the dark. After exactly four years had elapsed from the reading of that paper, Professor Huxley, my main helper before, took up the Amphibian skull once more (his earlier researches were partly given in his 'Croonian Lecture' delivered in November 1858); and this new work* resulted in the discovery of sundry errors and deficiencies in my account of the development of the Frog's skull. These criticisms given to me *orally* soon commended themselves to my own mind, now gaining greater light; and the great difficulty of the subject, a difficulty acknowledged freely by my friend and guide, has acted in producing the intensest desire in me for a fuller knowledge of these most instructive, if perplexing, types.

It was unfortunate for me that I took up by far the more difficult problem, namely, that of the skull of the 'Anura,' whereas that of the 'Urodela,' the Salamander and its companions, is a much simpler structure, undergoing much less metamorphosis.

Therefore the masterly account given by Professor Huxley of the skull of *Menobranchus*, a very low and simple type, has shed a most welcome light upon the skull of these air-breathing 'Ichthyopsida.'

We have now carefully worked, more or less in each other's view, at the structure and development of several types of skulls of the Anura and Urodela; and at last the truth of the matter seems to be revealing itself.

In the present paper I shall show, as I proceed, all those deficiencies and actual errors which now, after these years, and after fresh and much holpen labour, appear in the older memoir.

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* See the article on Amphibia in the new edition of the 'Encyclopædia Britannica,' and his paper on *Menobranchus* in the 'Proceedings of the Zoological Society,' March 17, 1874, pp. 186–204, plates 29–32.

This is, in itself, a most agreeable part of my work; and I hasten to sift away all that appears now to be untrue, however well winnowed it once appeared.

The advantages above mentioned are not all, nor even the greatest of those I have of late derived from the researches of my valued fellow-labourer; most suggestive and promising are the views which have lately been laid before the Society (Proc. Roy. Soc. Dec. 17, 1874, vol. xxiii. p. 127) on the *Amphioxus* and its structural relations to the Lamprey, its larvæ, and its kindred. This short paper is, if I am not greatly mistaken, of almost equal value with the 'Croonian Lecture'; if the author's deductions stand the test of further research, they will light up the darkest recesses of Vertebrate morphology.

I shall suppose the reader to be familiar with that communication, and it will be open to us now to consider the ordinary Vertebrata, or *Holocrania*, to be highly specialized and metamorphosed descendants of long-lost 'Entomocrania.'

In the latter the long, many-jointed skull may be compared to that part of a plant in which all the 'internodes' are developed; whilst the skull of ordinary Vertebrata may be likened to a *flower*, where the internodes are not developed, and where the foliar organs, being brought nigh to each other, coalesce in various ways and undergo remarkable modifications of form and of relative size.

At present I bring forwards corrected figures of the skull of the adult common Frog (*Rana temporaria*), and new results obtained by a study of the development of the skull of the common Toad (*Bufo vulgaris*), correcting, by these observations on equivalent stages, those which are imperfect or untrue in the first memoir.

In that paper the *figures* are seldom inaccurate, but both these and the descriptions will be brought now into comparison with these newer results.

After this has been done, I shall show the structure of the skull in various stages of the 'Aglossal' Toads—namely, *Dactylethra*, the Cape Toad with nailed paws, and *Pipa*, the remarkable Surinam Toad.

These will take up all the space available in a single paper; afterwards, my researches on the Bull-frog (*Rana pipiens*) and the Paradoxical Frog (*Pseudis paradoxa*) will, with others, be offered to the Society, and, also, as time and opportunity serve, figures and descriptions of the less-modified tailed types of Amphibia.

Such terms as are new in the present paper are adopted from the two memoirs of Professor HUXLEY just referred to; the gradual introduction of accurate morphological terms is not only desirable but absolutely necessary, yet these cannot be given before the true nature of the parts is understood.

In the Class of Fishes the specialization of the parts of the skull and face is greatest in the Teleostei, and least in the Marsipobranchii; the Elasmobranchii come nearest to the latter, the Ganoids nearest to the former; all these types of skull must be brought into light; of my own work only that on the Teleostean skull has as yet appeared.

One thing which misled me in working out the Frog's skull was the expectation of finding its development much more in harmony with that of the Teleostean type than it turns out to be.

As in the adult Urodelous Amphibian, so in the larval Anuran, certain parts are abortively developed or even quite suppressed.

In the metamorphosed young of the Common Frog and Toad these parts appear, but not until after the lapse of some time; this *anachronism* is much less in *Pipa* and *Pseudis*[*].

The advantage of working independently, and yet with constant intercommunication both by word and letter, with no little controversy and mutual criticism, seems to me to be very great; this has been of late more than ever the plan adopted by Professor HUXLEY and myself.

Many unresolved doubts still await further labour; and in some points of nomenclature I hold to what I gave in my former paper. In the account here to be given of the skull of *Dactylethra* and *Pipa* I shall give more time and care to even the adult skull than the author of the article "Amphibia" (just referred to); and, besides this, I have succeeded in obtaining early stages: thus I possess a sure key to the difficulties of the adult skull[†].

On the Skull of the adult Common Frog (Rana temporaria).—*Nasal region.*

Before my former paper was in print, I had seen and figured the free trabecular cornua projecting from the nasal capsule of the adult Bull-frog (*Rana pipiens*); but I had missed them in the common kind, and supposed that they were peculiar to the larger type. But, in his article "Amphibia," Professor HUXLEY figured and described them in *Rana esculenta* (p. 755, fig. 9, *r.p.*) as "rhinal processes." These are not shown in my figures of the chondrocranium of the adult *R. temporaria* ("Frog's Skull," Phil. Trans. 1871, plate ix. figs. 6 & 7). I doubted their existence in that type; but early in 1874 Prof. HUXLEY sent me a pen-and-ink sketch of them in this species, and I soon after found them myself (Plate 54. figs. 1, 2, *c.tr.*). The same letter gave the position of *one* of the two permanent upper labials (*u.l.'*); the other (*u.l.''*) was soon found by me, and then it was seen that much of the nasal outworks are formed, in the adult skull, of the greater segment of the originally simple upper labial ("Frog's Skull," plate v. figs. 3 & 4, *u.l.*). These, in the specimen figured in the present paper, were quite distinct from the true alinasal and aliseptal folds of cartilage; they may, however, become coalesced in the adult, as they certainly do in the Toad (Plate 54. figs. 3–5)[‡].

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[*] At present I can only compare the skulls of the *Anura* and *Urodela*, not having worked out the *Peromela* (Cæcilians); for an account of this type of skull the reader is referred to Prof. HUXLEY's description of the skull of the adult *Epicrium glutinosum* (Enc. Brit. art. Amphibia, p. 761).

[†] I have to thank Professor HUXLEY for the loan of adult skulls of *Pipa* and *Dactylethra*; Dr. DOBSON, F.L.S., of Netley, for another adult *Dactylethra*; my friend, Mr. T. J. MOORE, of Liverpool, for *nine* larvæ of various stages of *Dactylethra* (besides most valuable specimens of other kinds); Professor W. H. FLOWER, F.R.S., for permission to examine specimens of ripe young of *Pipa* contained in the Museum of the Royal College of Surgeons; and Dr. GÜNTHER, F.R.S., for tadpoles of that type.

[‡] The relation of the upper labials to the vestibule of the nasal labyrinth is of great interest; I have carefully worked out these parts in Sharks, Skates, Teleostei, Anura, Serpents, many kinds of Birds (Trans. Linn. Soc. ser. 2, vol. i. plates 1–5 and 20–27; and Trans. Zool. Soc. 1875, vol. ix. plates 54–62), and in the Mammal (the "Pig's Skull," Phil. Trans. 1874, plates xxxi.–xxxvi.).

The meaning of these facts will come out with great distinctness when I come to describe their development in the "Aglossal" Toads; and in all the Batrachia we have most instructive foreshadowings of the complex nasal labyrinth of the bird, and of the endless galleries of the ethmoidal and septal structures of carnivorous and herbivorous mammals.

At once it may be well to state that in those higher forms the distal ends of the trabeculæ, "hypotrabecular" or "recurrent cartilages," do not straighten out as in these Batrachia; but the hooked or retral condition seen in the Bird and Pig also occurs in many of the Batrachia. The median or keystone part (prenasal or basitrabecular cartilage) is but little developed in the Frog (Plate 54. figs. 1 & 2, *pn.*); it is more distinct in *Pipa* (Plate 62. figs. 5 & 6, *pn.*).

The actual end of the trabecular cornu remains as a shrunken pedate process with its "toe" turned to that of its fellow of the opposite side; this is the "rhinal process" of HUXLEY, whose figure (*op. cit.* fig. 9, p. 755) seems to show it as a distinct cartilage: it is, however, continuous with the outspread subnasal plate (*al.n.*) formed by expansion of the larval trabecular bar.

In the same figure the foliar outgrowths of the trabeculæ are called "prænasal processes" (*pn.l.*); they correspond to the distal part of the trabeculæ, and are very simple in birds and mammals ("Pig's Skull," plate xxxvi. fig. 1, *c.tr.*). Moreover, as the comparison of these parts in many types teaches me, the outer cervicorn part answers to the floor of the down-turned alinasal growths of the hot-blooded Vertebrata.

There is no appearance in the Frog of three distinct territories in the roof of the internasal plate such as we see in higher types, namely aliethmoidal, aliseptal, and alinasal laminæ, the plates whose outgrowths are the turbinals of those various regions. The trabecular floor (fig. 2) is the widest in front; the ethmoidal roof is widest behind (fig. 1). In the very front of the nasal sac the cartilage becomes laminated, a sort of attempt at the formation of turbinals ("Frog's Skull," plate x. fig. 3). Professor HUXLEY stated his doubts to me as to the existence of these laminæ; but *new sections* show the truth of my old drawings*.

The 2nd upper labial (*u.l.''*) is a solid club, with an out-turned and pointed handle; the 1st (*u.l.'*) is a pisiform cartilage, serving as a cushion on which the premaxillary rests. The annular ethmoid ("Frog's Skull," plate viii. fig. 7, *eth.*) is rightly represented in my 9th stage as beginning above as a transverse ectosteal bar; but the chondrocranium afterwards calcifies, and then becomes completely ossified; the fore-and-aft extension of this "os en ceinture" varies greatly in different types of Amphibia, as this paper will show; in *Lissotriton punctatus* the little skull becomes a very strong osteocranium.

Professor HUXLEY calls the fore part of the cartilaginous palatine bar the "antorbital process;" there is a pre-, post-, and superpalatine region here, the latter being the conjugational bar between the trabecula and the pterygo-palatine arcade, one of the

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* In the same plate the sections show the distinctness of the "2nd upper labial," which acts the part of an ala nasi (see figs. 3 & 6, *v.e.n.*). I did not at that time see the meaning of my own sections and drawings.

three swinging-points by which the first postoral is yoked on to the preoral bar in the Batrachia *.

On the Structure and Development of the Skull in the Common Toad (Bufo vulgaris).—*Last stage, adult.*

The figures illustrating the skull of the adult Toad show a chondrosteous structure, the chondrocranium with its soft tracts and its partially calcified and wholly ossified territories; the investing bones are faintly indicated by outlines.

For these latter bones are of much less morphological importance than the parts they cover in, being deep or shallow strata of connective fibrous tissue converted into regular bony tracts; the essential primary skull is early formed in hyaline cartilage, and tracing the development and modification of its elements is the difficult part of work of this kind.

This structure is now entirely continuous, with the exception of the antero-superior labials (Plate 54. figs. 3, 5, 6, *u.l.'*), and has been made up of the parachordal region, the whole of the foremost pair of bars (trabeculæ), the upper part of the first postoral (palato-quadrate), the impacted ear-sac, and the postero-superior labials. The main part, or cranial cavity, is an irregular trough or barge, which is flat above (fig. 3) and convex below (fig. 4). The lower surface is filled in by cartilage, with certain passages infero-laterally; whilst the upper surface is covered in in front, behind the middle, and near the end. Under the deck-like ethmoidal roof the cranial cavity is bored by the olfactory crura; behind, the great cavity is wide open for the large medulla spinalis.

In front, the entire bony girdle is the ethmoid, trespassing upon the orbito- and presphenoidal regions, which do not differentiate any proper bony tracts. The posterior sphenoid also gains the "larger wings" merely as an ongrowth of the large prootics (*pro.*). For here we see that the Batrachian skull takes an intermediate position between the Elasmobranchs, which have only a somewhat calcified chondrocranium, and the Teleostei, whose osteocranium is made up of many special bony territories. Here are no calcareous tesseræ, as in the Shark; but there is some disposition to the gathering together of the calcified tracts into larger plots, that, if finished within and without, would answer to the ordinary osteocranial bones. The girdle-bone (*eth.*) answers to so much of the mammalian ethmoid as would exist if bony matter were to surround the olfactory recesses (in that class multiperforate), run a little backwards into the fore edge of the anterior sphenoid, and harden a moderate tract of the perpendicular ethmoid. Here, in the Batrachian, we have these parts devoid of all those coiled outgrowths called turbinals; and yet, simple as these structures are, they are not easy to understand or to describe. In front of the girdle-shaped ethmoid three large cartilaginous growths project. The median growth is a vertical plate, the unossified continuation of the perpendicular bone; this is the septum nasi (*s.n.*). On each side of this middle wall the sinuous enfoldings of the olfactory or Schneiderian membrane lie. The openings into this labyrinth, or outer nostrils (fig. 3, *e.n.*), lie at a good distance from the septum, at its fore end. The openings by which this labyrinth communicates with the cavity of the mouth, the inner nostrils (fig. 4, *i.n.*), are also a good distance apart, opposite the hinder part of the septum, at least behind its middle. Now, unlike the eyeballs, which are permanently separate, and the ear-balls, which were so at first, but lose their independence, the nasal sense organ has no independent growth of cartilage; the main part is borrowed from the trabeculæ cranii, and the rest from the upper labials.

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* These two bars may be conjugated at *five* different points in the Vertebrata, namely, 1st, by the palato-trabecular or "antorbital;" 2ndly, by the orbital process, as in the Toad and Lamprey; 3rd, by the pedicle of the mandible; 4th, by the junction of the basipterygoids (external pterygoids) with the pterygoid bone; and 5th, by a sliding joint of the pterygo-palatine arcade (in its mesopterygoid region) on the trabecular beam, as in Birds.

For in the ethmoidal region the coalesced trabeculæ (see the early stages in Plate 55, soon to be described) not only grow together to form an 'internasal plate,' but behind this part, from their edges, a cartilaginous growth proceeds, which fills in all the interspace up to the hinder or parachordal region of the skull floor. Then, besides this, they grow up into a wall on this side and on that; and not only grow into side walls, but also develop cartilage, which divides the cranial from the nasal chambers, building in the foregrowing olfactory nerves (*crura*). Below, the nasal labyrinth is well floored; above, very imperfectly (figs. 3 & 4).

In the larvæ, as we shall see (Plate 55, *tr.*), the trabeculæ flatten out, and straighten out, instead of keeping the down-bent form acquired during the existence of the "mesocephalic flexure." The flattening out of these bands is similar to what we see in the Shark. The internal nostrils (fig. 4, *i.n.*) set bounds to these right-and-left laminæ towards the hinder third; they then become very large and leafy, each leafy plate sending out two lateral claws, one pointed and looking backwards, and the other obtuse and stretching forwards and outwards. Then, all of a sudden, the trabeculæ cease to grow, and their terminal part, or "cornua," project forwards and look inwards from the middle of the rounded fore edge of the nasal floor. These "cornua trabeculæ" are Professor HUXLEY'S *prorhinal* cartilages. These *distal ends* of this basal part are much smaller in the Toad than in the Bull-frog and our native kind (figs. 1 & 2, *c.tr.*).

From the broad, double, concave floor arises the partition wall, or septum nasi (*s.n.*), and from this wall a roofing-plate, right and left (fig. 3, *al.s.*). This roofing-cartilage is scarcely a third as broad as the floor, whereas in the Frog (figs. 1 & 2) it is the larger of the two. It is wider behind where it runs into the aliethmoid; and also in front it spreads, thickens, and shelves over into an oblique front wall, which has two round windows close to the front of the floor for the exit of the nasal nerves (fig. 5, *al.n.*, *n.n.*, *c.tr.*). On each side of these openings the outer nostril (*e.n*) is guarded by a thick, oval leaf of cartilage, the "1st labial" (figs. 3, 5, 6, *u.l.'*), a segment from the large single piece seen on each side in the Tadpole (see "Frog's Skull," plate v. *u.l.*). This cartilage is crested above at its outer part, whilst the inner, rounded end is enclosed in a fold of the premaxillary, the trihedral part lying between the arms of the curious horseshoe-shaped "septo-maxillary" (fig. 6, *u.l.′*, *px.*, *s.mx.*).

Possibly in old Frogs, certainly in full-grown common Toads, the second labial (*u.l.″*) coalesces with the chondrocranium.

The deficient roof arising from the septum nasi is here largely supplemented by the second upper labial (*u.l.″*). This is, on the whole, lanceolate, but it is twisted in a sigmoid manner, and is irregularly dentate, and even fenestrate, on its outer margin. The ends are narrow; the fore end has coalesced with the stunted alinasal cartilage (*al.n.*), and the hinder end with the *antorbital*, or palato-trabecular bar, near its junction with the ethmo-palatine (*p.tr.*, *e.pa.*) An irregularly crescentic membranous space separates the inner edge of the second labial from the aliseptal fold. This valve to the outer nostril corresponds to the "appendix alæ nasi" of the mammal ("Pig's Skull," plate xxxvi. fig. 1, *ap.an.*); and the small inturned cornua trabeculæ answer to the "recurrent cartilages" of the Bird and the Pig (same fig., *rc.c.*).

I spoke of lateral cartilaginous outgrowths from the chondrocranium in front of the girdle-bone. These, which look also somewhat forwards, are the "conjugational processes" that run out to unite the trabeculæ with the palatal bar. They are in the Toad (not in the Frog) instructively segmented off from the orbital process of the palatine or ethmo-palatine (figs. 3–5, *p.tr.*, *e.pa.*)*.

In front of the girdle-bone, where the olfactory crura pass out, the true olfactory region is the recess on each side, backed by the narrow antorbital, on which no "middle turbinal" is formed; roofed by the "aliethmoid" and aliseptal (from which there grows no "upper turbinal" behind and above, nor "lower turbinal" in front and then below); and is floored by the outspread, concave, subnasal trabecular leaf. Laterally in the skull there is no true bone from the girdle in front to the great openings for the 2nd and 5th nerves behind. Infero-laterally, the prootic bone (*pro.*) creeps along the alisphenoidal region, half embracing the great optic passage (2). Further back each prootic seeks its fellow, but stops short a little within the edge of the parasphenoid; enough, however, is found to enclose the trigeminal nerve (5), the *foramen ovale* and *foramen rotundum* being all one passage, and enclosed by the "petrous bone" (*prootic*). A line drawn through the cranial trough a little in front of the hinder edge of the girdle-bone, and another through the middle of the optic passage, would be true landmarks of the anterior sphenoid, which we see is soft, or partially calcified (superficial endostosis), or has a borrowed bony margin (in front). All that part of the prootic which encloses, and lies in front of, the trigeminal nerve is a bony trespass on the posterior sphenoidal region, whose bounds are from the optic passage forwards to the hinder surface of the trigeminal.

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* This segmentation throws light upon the connexion of the palatine with the *ethmo-trabecular* structures in the Vertebrata generally. In the lower Urodela, *e.g.* *Proteus* and *Menobranchus*, the ethmo-palatine bar is all that is chondrified of the pterygo-palatine arcade (HUXLEY, on *Menobranchus*, Proc. Zool. Soc. March 17, 1874, p. 190, pls. xxix., xxx., *A.o*). In these the trabecula grows out towards this palatine rudiment, but not so much as in the Toad. In the Frog (figs. 1 & 2, *e.pa.*, *p.tr.*) the two bars run into each other. In the Salmon there is a joint ("Salmon's Skull," Phil. Trans. 1873, plate vi., *e.pa.*), and as a rule the orbital or ascending part of the palatine is distinct from the trabecular outgrowth; the ethmo-palatine, in many Birds, is developed into the very variable "os uncinatum." (See Trans. Zool. Soc. 1875, pls. liv.–lxii., for several instances of this bone in the Passerines.)

As in the Ichthyopsida generally, the posterior sphenoid seeks to become (in the chondrocranium) a perfect girdle—a "sclerotome." Here, as in the anterior sphenoid, the trabeculæ have each a mural upgrowth; but in this part the wall-plate thickens, and a ceiling is thrown over, which, however, is narrow near the side and then wide at the middle, where it is fused with the *occipito-otic* ceiling. Such a conformation leaves *skylights* in the ceiling of an oval form; these are the posterior *fontanelles*, a little behind the square, main fontanelle (*l.fo.*, *fo.*); and both these are filled up with a parchment of strong fibrous tissue, and roofed with a large shingle of fibrous bone—the fronto-parietal (*f.p.*).

But the wall and its wall-plate in the posterior sphenoidal region is a solid concrete of endosteal bone, thinly enamelled by ectostosis. The ceiling, above, is mostly unossified up to the edge of the foramen magnum; but, below, the prootic bones, laterally, have only a narrow tract of cartilage separating them from the exoccipitals, which bones, without a basioccipital threshold or a superoccipital keystone, are all that appertain to the occipital girdle-bone. Above, the prootics are most, and the exoccipitals least; below, the contrary takes place (figs. 3 & 4, *pro.*, *e.o.*). Thus, below, a cross of cartilage is seen dividing the bones before from the bones behind; and this soft part is more than floored by the cross-shaped parasphenoid (*pa.s.*). The ear-sacs, which in the larva (Plate 55, *au.*) were little cartilaginous egg-like bodies, are now, through the development of the great tubular arches above and the sacs below, distended into a new shape from within. And to this modification by the swelling and rising within of the ear-labyrinth is superadded the coalescence of the auditory mass itself on its inner edges with the skull, and the fusion with it on the outside of the facial bars.

Nothing but a careful analysis of these outstretching wings, and a knowledge of the history of their growth, could give any adequate idea of their meaning. Their structure will be described now, and their development next (see Plate 55).

Above (fig. 3, *pro.*), we saw that the prootic had hardened the wall-plate in the posterior sphenoidal region; behind that part it forms a roof to most of the anterior semicircular canal (*a.s.c.*). The bony growth then fails on the inner side, and at the junction of that canal with the posterior (*p.s.c.*) there is only cartilage *unusually calcified*, an initial "epiotic" bony centre (*ep.*). This rounded, arched elevation has its convex edge limited by the exoccipital (*e.o.*), and its concave or outer edge by the prootic. The prootic then dips, where it lies over the interspaces of the semicircular canals, but is convex again where it enroofs the horizontal canal (*h.s.c.*); it then forms a sudden, sinuous margin, leaving unossified a large ear-shaped mass of cartilage at the outer edge of the occipito-otic wings: this free, soft part is the "tegmen tympani."

This latter part is thick at its edge, runs forwards, then passes inwards, and slopes downwards and forwards into the scooped anterior face of the auditory mass (fig. 3). In front the tegmen is continuous with the "otic process" of the mandibular pier (*ot.p.*).

The foramen magnum is largely open on the upperside (fig. 3, *f.m.*); thus, being oblique, it seems to be a heart-shaped space, for its outline is narrow and rounded above, bulging at the sides, and emarginate below. This emargination, where the notochord has been aborted, is the end of the parachordal plate, at its middle. On each side of this there are the right and left occipital condyles (*oc.c.*), having a core of bone and a bark of cartilage.

The exoccipitals are pinched in outside the condyles, and they elegantly expand to receive and to enclose the large posterior canals. This is above (fig. 3, *e.o.*, *p.s.c.*); but below (fig. 4), the bone, true to its Batrachian nature, occupies all its own and also the "opisthotic" territory (see also fig. 7).

The hypoglossal nerves do not pierce, but pass out *behind* the occipital; but the exoccipital bone enrings the nerves that pass out of the chink between the occipital arch and the ear-sac. These are the glossopharyngeal and vagus (9, 10); they are separated by a bar of bone, which divides this foramen into two*.

The *opisthotic region* of the exoccipital (figs. 4 & 7, *e.o.*) is seen below the vestibule, in front of the double foramen (9, 10), and outwards to the hinder edge of the stapes (fig. 7, *st.*). Here it is seen growing downwards as a hook, whose concave face is forwards. This roughly represents the bar which, in the higher types, separates the *fenestra ovalis* from the *fenestra rotunda*, and which, in the Crocodile, forms a ring round the neck of the cochlea (HUXLEY, Elem. Comp. Anat. p. 223, fig. 89, A, *Op.O*, *c*, *Chl.*). In fig. 7, where most of the tegmen tympani (*t.ty.*) has been cut away, the extent and relations of those two great bones, the prootic and the exoccipital, are well seen, as also how near they come to each other.

As my views upon the meaning and nature of the parts of the facial bars attached to this auditory mass have undergone much change, owing to Professor HUXLEY'S criticism, his own work, and my renewed research, the description that follows will be found to differ in several particulars from that given in my paper on the Frog (see also, HUXLEY, "On *Menobranchus*," Proc. Zool. Soc. March 17, 1874, and his article on the "Amphibia," Encyc. Brit. new edit.).

The dorsal ends of the mandibular and hyoid arches have been the most difficult parts to work out, owing partly to developmental *anachronism*, and partly to their relation to the auditory mass, and the metamorphosis dependent upon, and ruled by, that relation.

The manner in which the mandibular pier is attached to the auditory mass is best seen from below (fig. 4); its apex originally passed into the trabecula, on its outside near its end (Plate 55); but afterwards it also contracts an adhesion with the fore face of the auditory mass.

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* I must now change the *number* of the nerves, and pass from the "old style" to the new. Henceforth the portio mollis is to be marked as 8, and not 7 *a*, and the glossopharyngeal and vagus 9 and 10, and not 8 *a* and 8 *b*.

It can be traced nearly up to the outer edge of the prootic (fig. 4, *pro.*, *pd.*); and this coalesced "pedicle," before passing into the mass of the quadrate (*q.*), gives off, from its posterior edge, a rounded condyle (*c.pd.*); this is much smaller than in the Frog (see "Frog's Skull," plate ix. figs. 2 & 7, *i.h.m.*)*. This coalesced bar and the condyle upon it are formed out of the primary apex or dorsal end of the mandibular visceral arch (Plate 55); but the "pier" also attached itself to the otic mass, *above*, by the "otic process" (fig. 4, *ot.p.*).

This process also coalesces with the auditory mass, namely, to the front of the tegmen tympani (figs. 3 & 4, *t.ty.*, *ot.p.*); it is an upgrowth from the *elbow* of the pedicle (Plate 55) as the *condyle* is a downgrowth.

From the point where these parts unite with the ear-mass there is a large fore-and-aft growth of cartilage; that behind, which curves also downwards, is the quadrate (*q.*); that which runs forwards is the pterygoid. The hinge of the quadrate nearly reaches backwards as far as the occiput, to give size to the gape, a state of things acquired during growth.

The pterygoid (*pg.*) runs forwards, wide at first and narrow afterwards, from the pedicle, and its lower part is continuous with the inside of the posterior margin of the quadrate. Midway to the antorbital region the flat tape-like pterygoid stops; then there is a tract of fibrous tissue, and these fibres fasten the pterygoid to the narrow postpalatine band (*pt.pa.*). As in Passerine birds, the palatine sends out an angular transpalatine process (*t.pa.*); it then runs forwards, retaining its larger breadth, curving a little inwards, and sending up the "orbital process" or ethmopalatine (*e.pa.*); it then ends in a free prepalatine spike (*pr.pa.*), whose flat upper end is attached by fibrous tissue to the palato-trabecular outgrowth. All this *prequadrate* growth is a development of the conjugational bar that ties together the anterior third of the 1st and 2nd bars in the skull of the embryo (Plate 55). In the Frog there is not any segmentation, either between the palato-trabecular bar (figs. 1, 2, *e.pa.*) or between the pterygoid and palatine ("Frog's Skull," plate ix.). The free mandible of the Toad is quite like that of the Frog; the "inferior labials" are not lost; they ossify as mento-Meckelian bones which unite with the small dentary, and the ends of these are mutually united by an elastic ligament. The articular region and much of the rod is enclosed in an *ununited* ectosteal "articulare"†. The next arch presents, perhaps, the most difficult problem in morphology; I have in the adult only figured the upper part; that which corresponds *to the whole* of the hyoid of the Urodela (HUXLEY, " On *Menobranchus*," plates xxix., xxx., *hy.*) has its apex only figured.

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* I mistook this for part of the "hyomandibular;" it is there called the "infra-hyomandibular" (*i.h.m.*). In the adult Frog the pedicle cannot be traced further up than this condyle; it, apparently, becomes fibrous above. I find that the bony plate which covers the inner face of this pedicle is much more distinct in the Bull-frog; it is the "metapterygoid," and in the latter species there is a small "mesopterygoid" as well. In the Toad the pterygoid proper covers the diminished condyle.

† Professor HUXLEY (art. "Amphibia," p. 753, fig. 6, *an.*) calls this bone the "angulare;" but it is united to the hardened rod itself in the "Aglossa," as in the Sauropsida.

In the Batrachia there is an *antero-superior* rod intimately connected with the " stapes " (*st.*); but in most Batrachia (not in *Pipa*) it is *late* in its development. The antero-superior palatine and the fore-turned part of the mandibular arch are also late; and both in Teleostei and Ganoidei amongst the Fishes, and in all the air-breathing Vertebrata, this region, the " pterygo-palatine arcade," is behindhand in growth, and suffers an extraordinary amount of metamorphosis. The mandibular is, as it were, a double arch.

So also is the hyoid an arch, which becomes subdivided into, or develops separately, *in an untimely manner*, two distinct and very dissimilar facial arches.

Its morphology is very varied in different groups; in the Shark the segment called hyomandibular forms a hinge with the distal part or stylo-cerato-hyal; they are related like a rib and sternal rib, or like the quadrate and the free mandible.

But that change in the disposition of parts which suggested to Professor HUXLEY the term *hyomandibular* is seen in the Skate, in the early embryo of which the hyoid arch is seen to chondrify into, (1) an antero-superior segment, broad above and having a round point below, which lesser end is tilted upwards and forwards, and is strongly articulated to the pier of the mandible; and (2) the proper, gill-bearing hyoid arch, which is separately attached to the skull.

In the Salmon it is otherwise (see " Salmon's Skull," plates i. & ii.); for in that type the hyoid chondrifies as one bar on each side, which splits almost from top to bottom (a little obliquely), and then the anterior segment becomes changed in form, tilted, and articulated with the inner face of the quadrate, to form the characteristic hyomandibular *swing*. The hinder piece, and a short segment from below, becomes the proper functional hyoid arch, and is swung by a secondary (" interhyal ") bone from the antero-superior piece, just within its middle part. It is perfectly plain that the hinder piece in the Osseous Fish, and the short distal segment, the " hypo-hyal," correspond to the long and short pieces of the hyoid arch of *Menobranchus* (*op. cit.* plates xxix. & xxx., *Hy*, *Hh*, and *ch.*), and also to the undivided, *low-hung* hyoid of the larval Batrachian (Plate 55, and *infra*). The gradual *ascent* of that bar and its change of form was traced in my paper on the Frog; in that type it ultimately *articulates* with the antero-inferior ridge of the auditory mass, below and in front of the fenestra ovalis and stapes. In the common Toad (Plate 54. figs. 4 & 7, *st.h*) it is thoroughly fused with the periotic cartilage at the same point. In the figure just referred to the tegmen tympani is cut away to expose the facial attachments, and above the massive stapes (*st.*) there is seen a partly ossified bar having, on the whole, the same relation to the cerato-hyal that the upper tilted segment has in the Skate.

In that type this part is not ossified, but in Osseous Fishes it acquires two ectosteal sheaths, and becomes two bones, united by synchondrosis (" Salmon's Skull," plates v. & vi.

h.m., *sy.*). The specialization in the Toad is in one respect different from what we see in the Fish; for the distal end of the bar in the former passes *outside* the quadrate, and in the latter on the *inside*. But both *inside* and *outside* are secondary relations altogether, as may be seen in the position of these parts in embryo Teleostei and in the Sturgeon, where the lower segment of the antero-superior piece is simply placed *behind* the quadrate (see 'Monthly Microscopic Journal,' June 1, 1873, plate xx. fig. 1, *sy.*, *q.*). In the Frog and Bull-frog the antero-superior bar is in two segments, as in the Sturgeon; in the Toads (*Bufo* and the "Aglossa") the bar is ossified as a larger proximal and a smaller distal bony rod, without segmentation of the intervening cartilage. Also, in the young of all, and in most Teleostean fishes, the head of the hyomandibular is unossified, and the foot or distal part of the "symplectic" or terminal piece. Moreover, Professor HUXLEY, who has shown me the great difficulties here to be encountered in the interpretation of the parts, knows full well that the portio dura nerve passes *over* the columella of the Toad and the hyomandibular of the Fish alike. One more remark: if the parts here taken to be the hyomandibular and symplectic, although modified to form the curious auditory "columella," are not developed at the *same time* as the hyoid bar, neither are they contemporaneous with the stapes, into which category Professor HUXLEY seems inclined to place them. Further evidence will turn up in the embryo of the common Toad, and also in the development of the "Aglossa" (*infra*); to my own mind the stapes is a *new thing* in the Amphibia, not existing in the Fishes; and when an antero-superior bar is developed, as in the Batrachia, its upper segment is the hyomandibular, and its lower the symplectic, whatever names these parts may receive on account of their auditory modifications*. In this, as in other Toads, the columella is a very elegant structure (Plate 54. figs. 7 & 8); its parts take their names from their stapedial (auditory) relations. As in the Frog, the fenestra ovalis is a window lying in a deep recess of the side wall of the ear mass; that recess is mainly filled by the irregularly oval, lenticular stapes, whose flat face is applied to the fenestra, whilst the convex face looks outwards.

The proximal part of the columella is shaped like a planting-"dibble," but the conical end is all soft, and the ensheathing bony shaft narrows and twists itself as it runs forward (fig. 8, *it.st.*). The rounded face of the subconical part fits against a shallow notch on the antero-superior edge of the stapes, and its inner face lies in the *recess*. Considered as a *segment* this answers to the short "interstapedial" of the Frog (*op. cit.* plate viii. fig. 9, *it.st.*).

But that which forms the main bar in the Frog, the "medio-stapedial," is here one fourth only the length of the proximal piece, and is a very small cylindrical bone. The two bones fit close together, and the end piece leaves much cartilage unossified—a soft-ended "symplectic." The soft part bends at right angles upon the little "medio-stapedial" (*m.st.*), and suddenly dilates into a large plate, like the blade of a spade; this is the "extrastapedial" (*e.st.*). This plate, which has some calcified patches, sends upwards and backwards from its inner face a band of cartilage which coalesces with the tegmen tympani; this is the "suprastapedial" (*s.st.*). In the Grey Frog this part does not coalesce above; in the Bull-frog it does. The relation of the extrastapedial flap to the membrana tympani is shown in the side view (fig. 7, *e.st.*, *m.t.*); it is imbedded amongst a rather loose gauze of fibres, which arise from the shelving outer surface of the thick-edged crescentic, cartilaginous "annulus" (*a.t.*). This part was developed, originally, from a little trifoliate cartilage which, in the larva, bridged over the space between the *elbow* of the mandibular pedicle and the tegmen tympani; it detaches itself and becomes crescentic*.

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* It cannot be an unmeaning fact that, whilst the Frogs subdivide their columella into two segments of cartilage, as in the Sturgeon, the Toads should have theirs marked off into two parts by two separate bony rods, as in the Osseous Fishes.

The portio dura passes *over* the "medio- and inter-stapedial" bar, but when its fibres come across the "annulus," they pass *beneath* it; in the larvæ of *Dactylethra* (*infra* Plates 56 & 57) the early conditions of the *annulus* and *tegmen* are so remarkable, that even Professor Huxley himself was doubtful (before he ascertained for me the course of the portio dura nerve) as to whether these were not the rudiments of the huge columella of that species.

There remain to be described the investing bones; these are faintly shown in the figures for the purpose of a better display of the fundamental cranium: they are very similar to those of the Frog ("Frog's Skull," plate ix.). Above, the principal bone is the fronto-parietal (*f.p.*); each double bone keeps distinct, by a suture, from that on the other side. The nasals (*n.*) are large convex plates, subtriangular above, and sending down a process to join the face, where the maxillary, palatine, and pterygoid meet.

Below, the great dagger-shaped parasphenoid (*pa.s.*) has the basitemporal *haft* with a point at the end of each process, and not abruptly truncated as in the Frog; these processes are nearly as large as the blade. Each vomer (fig. 4, *v.*) is a 4-sided bone, concave below, toothed in front, and emarginate externally. The palatine (fig. 4, *pa.*) is a thin *knife* of bone, passing from the outer part of the cartilaginous bar to the edge of the parasphenoid, almost transversely, but a little deflected towards its inner end; this and the following properly belong, not to the *parosteal*, but to the *ectosteal* series. The pterygoid (fig. 7, *pg.*) is a curious obliquely triradiate bone, convex below, where it wholly invests the cartilage, and concave above, where it leaves it somewhat exposed at the end. Its arcuate front spur reaches the transverse palatine bone, its inner spur runs up beneath the pedicle and aborts the metapterygoid, and its external spur runs backwards, forming a strong splint to the inner face of the quadrate. A bony sickle (*q.j.*), representing in one piece the ectosteal plate of the quadrate and the quadrato-jugal of the *Sauropsida*, is strongly attached by its broad end to the quadrate outer face, is overlapped by the handle of the squamosal (*sq.*), and has its convex ridge attached, in front, to the jugal process of the maxillary (*mx.*). The great hammer-shaped temporal (squamosal, fig. 7, *sq.*) in its upper part rides over the auditory mass, and sends forwards and outwards a postorbital process; its handle is largely enclothed with the tympanic curtains; but the lower end is apparent, overlapping both the quadrate cartilage and its bony style.

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* See "Frog's Skull," plates v.–vii., where it is lettered, both in its attached and its free stage, as *s.h.m.*; for I was deceived by it, and took it for the rudiment of the "columella auris."

I have already described the lower bones of the gape; there now remain the upper. The whole bony arch is thrown round the upper face, and reaches nearly to the quadrate by the jugal process of the maxillary. This bone gradually broadens to its fore part, is abruptly truncated in front, and sends upwards a process to articulate obliquely with the anterior edge of the descending crus of the nasal. The arcuato-oblong premaxillaries (*px.*) form a double keystone to the great arch; they fit by straight surfaces to each other and to the maxillaries. The nasal process of the premaxillary (fig. 6, *n.px.*) is large and convex; the palatine process is a short spur bounding the inner end of the emarginate posterior margin, below, as in the frog (*op. cit.* plate ix.). There remain two bones to be described: these are the "cornets" of DUGÈS, my septo-maxillaries (fig. 6, *s.mx.*, and "Frog's Skull," plate ix.). Professor HUXLEY (art. "Amphibia," p. 754) did not observe them in *Rana esculenta.*

In the Toad (fig. 6, *s.mx.*) they are unusually large and well developed; in shape they are *hippocrepiform*, and, indeed, their likeness in outline is great to the shoe of a horse turned up for the frost, but the sides are largely connected by bony matter. The antero-superior labial (*ul.l'.*) has its round inner end encased by the premaxillary, but the trihedral blade rests on the upper face of the septo-maxillary*.

Structure of the Skull in Bufo vulgaris.—*First Stage. Embryos one third of an inch (4 lines) long.*

At this stage the external branchiæ are becoming short, and the internal are just developing. It corresponds to the *third stage* as given in my paper on the Frog's Skull (plate iv. figs. 7–12).

Before describing this stage in the Toad I shall show the weak points in the former paper.

In the earlier stages (1 and 2) I find no error as yet; but the facial parts are coloured lilac, as though they were cartilage, when they are still only very solid indifferent tissue.

In the figures showing the auditory sac the open membranous space is shown as though it were supero-lateral, whereas it is superior in position.

In the third stage this is figured and described as filled in (plate iv. fig. 7, *au.*), whereas it is open for some time afterwards. In the same figure is to be found that mistake which became the parent of several more. The hyoid arch is figured as two cartilages

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* The term "cornet," or *turbinal*, is wholly inapplicable to this bone; it answers to one of the "preorbital series" of a Ganoid or Teleostean (Siluroid) fish, and reappears, in a specialized form in relation to the nostrils, not only in the Batrachia, but also in Snakes and Lizards, where it has its fullest development, and in Birds, whose palato-nasal structures are metamorphosed to the utmost.

(*hy.* and *h.m.*); the upper (*h.m.*) is merely the outer edge of the mandibular pier (figured in its lower part as *qu.*); the part answering to the hyomandibular of a fish does not chondrify until several weeks (4 to 6) after the metamorphosis of the larva is apparently complete, that is, until early summer.

As I have already stated, the part in the succeeding figures lettered as *i.h.m.* is only part of the *pedicle* of the mandible, and not an infrahyomandibular; whilst *s.h.m* is not the upper part of that bar, but the rudiment of the "annulus tympanicus." The remaining things to be noticed are deficiencies: thus the fore part of the chondrocranium of a newly metamorphosed frog (plate vii. fig. 11) does not show the subdividing labial on each side. Also, there is this deficiency in the figures of the adult chondrosteous cranium: the second upper labial is somewhat displaced (figured *al.n.*), as though it were the alinasal fold; the first labial is not drawn, and also the prorhinals, or cornua trabeculæ, were missed. The lower figure, but for the absence of the little pedate cornua (see Plate 54. figs. 1 & 2, *c.tr.* of the present paper) is quite correct; and I have there truly lettered the bony plate formed on the condyle of the pedicle as *m.pg.* It is the metapterygoid, but does not cover any *coalesced part* of the hyoid arch. In plate x. the second labial is correctly shown as distinct, but incorrectly lettered *al.n.* (figs. 3 & 6).

In the diagrammatic figures (11–20) the third (fig. 13) is incorrect (as in plate iv. fig. 7). The others are correctly drawn, but the colouring is wrong from 13 to 19. There should be no hyoid colour (lilac) on the back of the great mandibular pier, as we now know that no part of the hyoid arch has coalesced with it.

The development of Frog and Toad is so precisely alike, that the observations now to be given relate to both equally. Professor HUXLEY worked mainly at the young of the Frog, and my new results have been obtained from the Toad.

The reader must compare my results in this early stage of the Toad's skull with those of Professor HUXLEY on the Urodelous Axolotl and Newt (*op. cit.* "On *Menobranchus*," plate xxxi. figs. 1 & 2).

In this stage I have merely figured the trabecula and anterior arches (Plate 55. figs. 1 & 2). The branchials (indicated in fig. 2 by outlines) are simple arcuate rods, beginning to coalesce at their ends.

But all the seven pairs of arched rods were at first quite distinct (see "Frog's Skull," plates iii. & iv.); they lay very close together, were very massive relatively, were composed of a rather solid mass of young cells, the outer of which could be seen as differentiated from the inner by a clear line, the first indication of the separation of the perichondrium from the cartilage within. These formed a very regular series, but the first pair of bars were most tilted upwards and were the largest.

By the time, however, when the external gills are beginning to disappear, the larva is one third of an inch in length; these arches, then, are formed of clear (hyaline) cartilage, sharply defined from the fibrous tissue cells that enclothe it as its perichondrium. Moreover, the change of *substance* is correlated with a change also of *form*. Each bar has assumed a series of curious bendings (Plate 55. figs. 1 & 2); the second, or mandibular, has developed a free bud at its distal end, and has united itself, by its proximal end, and also beyond its middle, to the first bar. The first of these two pairs of *conjugations* show the first condition of the union of the pedicle of the mandible (*pd.*) with the elbowed part of the trabecula (*tr.*) near its apex, and the second the rudimentary pterygo-palatine arcade (*p.pg.*). The bud of cartilage at the free end of the second bar is the free mandible (articulo-Meckelian rod), and all the rest is its suspensorium. The upper part of the hyoid arch has not become chondrified; the lower part, or cerato-hyal (fig. 2, *c.hy.*), has become very much flattened out, and, pressing its antero-superior angle against the superior margin of the arch in front of it, has begun to form a remarkable *temporary* articulation, with a joint cavity. Besides the visceral arches, the ear-sacs are now enclosed in a cartilaginous capsule (*au.*), which is unfinished at the upper part.

Save the branchial arches and the parts just mentioned, there is no other cartilage in the cranio-facial basketwork at this stage, for the "parachordal" region (*nc.*) is still membranous.

The first pair of bars, or trabeculæ, extend from their *posterior end*, which overlaps the fore end of the notochord, to the frontal wall of the face, their anterior ends running up to the cartilages that form the thickness of the upper lip (*u.l.*, here shown in outline). On the whole, the figure made by the trabeculæ is lyriform, but the bars are bowed and bent in the manner of gnarled branches. The apical or hinder part is bent suddenly inwards, at little more than a right angle, and this part is terete, with a round and somewhat knobbed end. Then the bar thickens, and, being bent on itself at nearly a right angle, it runs convergingly inwards. This is done twice, the second time in a crescentic manner, suddenly; and thus the right and left bars are brought fairly into contact, their free ends flattening somewhat and then becoming clubbed (like the apices), these swollen, distal ends looking outwards, away from each other. Thus, with the round end of the notochord stopping the gap behind, we have a *pituitary space* of huge relative extent; it is heart-shaped, with an anterior acuminated apex and somewhat concave sides.

There are the rudiments of two "myotomes" (mt^1, mt^2) on the sides of the huge notochordal extremity, which is somewhat pinched at its waist; but there is no parachordal cartilage. The soft tissue which lies on the muscular segments rapidly chondrifies after this time; so rapidly that in a few days there is no distinction of trabecular and parachordal cartilage (fig. 3, *tr.*, *iv.*). Thus the trabeculæ show their independence by their *priority*; they are perfect for several days before the investing mass (parachordal region) is chondrified.

In this model and platform of a skull the *ear-balls* are as independent as the *eye-balls*. At present all the cartilage that exists is *below*. The cranium, save at the base, is a "membrano-cranium," and the nasal qouches are soft membrane.

The posterior or outbent elbow has the pedicle of the mandible conjugated to it; the anterior inbent elbow touches that of its fellow of the other side, and these two cartilaginous knuckles form the foundation of the nasal superstructure; by touching, they begin to build the "internasal plate." The clubbed ends will be the lower part of the nasal labyrinth; they send out the free "prorhinals." The gentle outbend of the trabeculæ, where the fore part of the next bar conjugates, will lie as the foundation-stone to the lateral ethmoid; it is the antorbital region. These bent rods have the cranial bag resting upon them; the pituitary body dips in front of the end of the notochord ("Frog's Skull," plate iv. fig. 8); and the "third vesicle" lies on the notochord and the gelatinous tissue which invests it.

The first postoral arch ("first visceral arch" of embryologists) is bowed and bent much after the fashion of the trabecula. Its apical part is bent suddenly inwards; and then the bar, in growing forwards, also turns inwards, subparallel to the other; but curving somewhat outwards, as the trabecula does somewhat inwards, there is a space left of an oval form—the "subocular space," or "fenestra" (*so.f.*). Before this second bar gives off the pterygo-palatine rudiment (*p.pg.*), on the other, or outer, side it is cupped for the head of the hyoid *half-arch*. The rest of the main bar then curves inwards towards the outbent trabecular horns (*c.tr.*), and ends in a rounded condyle, which fits in the hollow proximal end of the Meckelian bud (*mk.*), an ovoidal nodule of cartilage, cupped above and rounded below. This free mandibular rudiment looks towards its fellow, and not from it, as in the case of the *continuous* distal region of the trabeculæ. The nasal passage lies over this little nodule, and opens into the palate in front of the pterygo-palatine rudiment (see figs. 2 & 3).

The next arch, whose lower half only is developed, corresponds now to the lower piece in the hyoid of a Shark, and to the *whole* of what appears in a tailed Amphibian (HUXLEY, "On *Menobranchus*," plate xxix. *Hy*, plate xxx. *Ch*). Its low position corresponds with that of its homologue in the adult Osseous Fish ("Salmon's Skull," plate vi. *ep.h.*, *c.h.*). In that type it has descended gradually, after its segmentation, from the primary bar; here, in the Toad's larva, the hyoid arch chondrifies only in that low part; and for the remainder, above, we must look three months afterwards, some weeks subsequent to the escape of the creature from the water. The articulation of this bar, which is properly the *postero-inferior* segment, failing the *front* and *upper* part, or hyomandibular, articulates directly with the posterior face of the mandibular pier. I am now perfectly satisfied that this connexion of the hyoid with the mandibular arch is the only one that takes place during larval life.

The form of the cerato-hyal at this stage (Plate 55. fig. 2, *c.hy.*) is oblong; it is curved externally and flattish within. Of the upper angles the anterior is rounded (as a condyle), and the posterior produced and leafy; so are both the lower angles. Between the right and left bars there is a nodule of cartilage (*b.br.*), which becomes the larger basibranchial behind, and the lesser basihyal in front.

Besides the branchial arches there are two pairs of labials (upper and lower, *u.l.* & *l.l.*). Thus, altogether, at this stage there are as *chondrocranial* elements already cartilaginous, seven pairs of bars, two pairs of labials, and one pair (we do not count the *eye-balls*) of "paraneural" elements.

Most of the cranium, therefore, is "membrano-cranium;" but the foundations of this small "lodge" are fairly marked out, and are rapidly solidifying by chondrification.

It is open to me to remark how that this type, even at its early stage, only gives evidence of possessing *two* "somatomes"* in its head. However complex what we call the *skull* becomes, it is largely built up upon the foundation of the trabeculæ cranii, these being the chief elements. The hinder third of the skull is parachordal.

A figure like this (fig. 1) would have made a proper series in Professor HUXLEY'S valuable plate ("On *Menobranchus*," plate xxxi. figs. 1 & 2, *Siredon* and *Triton*). In all the three we see, fairly, in the interauditory or occipital region, two myotomes. Those Urodelous types differ from the larval Toad and Frog in the early appearance of the bony plates; they come very much later in the Batrachia.

Skull of Bufo vulgaris.—*Second Stage. Tadpoles 5 lines long.*

During the time in which one of these larvæ is one fifth longer, the head has grown twice the size, and the development of the parts has gone on very rapidly. The external gills are no longer apparent, and the form and appearance is that of a perfect *bull-head.* The chondrocranium at this stage (fig. 4, a *half-figure*, seen from below) is much more perfect than in the last, for the gelatinous stroma that lay over the myotomes on each side of the notochord has become hyaline cartilage. I cannot view these parachordal tracts (*iv.*) as the growth backwards of the apices of the trabeculæ, but as quickly transformed cells, the fore margin of whose territory is lost in the trabecular tract (*tr.*) as soon as the solidification takes place. The notochord (*nc.*) has retreated, and has its fore margin bounded by a solid belt of cartilage, from which on either side the parachordal bands run, binding on the sides of the notochord, and ending behind in the occipital condyles. In the Salmon-fry of the second week after hatching (my 5th stage, *op. cit.* plate iv. p. 127) the trabeculæ and "investing mass" are quite distinct, the former *crossing fingers* with the latter in a most evident manner. Here, where the chondrification is not synchronous, there need, surely, be no difficulty in the interpretation of the parts: they are distinct in the Newts.

The trabeculæ, which pass forwards as broad, flattish bands, have coalesced in front, forming an internasal plate (see also fig. 3), and now their large flat cornua (*c.tr.*) are falcate, with a slightly notched convex margin.

The pituitary space enclosed by them, under the middle brain, is now more regularly oval; and the subocular fenestra formed by the trabecula and mandibular pier is now widest at its hinder part. A *prenarial ligament* (*p.n.l*) connects a tooth-like process on the outer edge of the trabecula with the inner face of the quadrate (*q.*) near the hinge. This ligament is cartilaginous in the next type (*Dactylethra*), and is an important structure in *Rana pipiens* and *Pseudis paradoxa*. Between this ligament and the broad, flat, pterygo-palatine band we see the valvular "inner nostril" (*i.n.*). In the former stage the trabecular elbow was the greater of the two; now it is the mandibular, which projects most (fig. 4, *pd.*), the fastened band running in a loop-like manner a little distance in front of the ear-sac (*au.*), arching round its front convexity. The second bar thus, in an outwardly arched manner, curves inwards to the other, or pterygo-palatine binder; its last *fifth* is free; this is the quadrate cartilage; it ends in a rounded condyle, on which the sinuous face of the free mandible (*mk.*) is hinged. At the middle of its side and a little below there is a notch and a subconcave facet, in which the hyoid (*c.hy.*) rolls; between them there is a joint cavity. Above this part is the "orbitar process;" this will be described in the next stage (fig. 3, *or.p.*). The small, free mandible (*mk.*) is somewhat arcuate, clubbed at its distal end; has a sinuous notch for the quadrate, and a large, solid angular process.

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* The Urodela in an early stage show a subdivision of the notochord into two rudimentary "centra;" this is best seen in the larva of *Seironota perspicillata*. Most of them, thus, have a rudiment, in this way, of a basioccipital, which represents two or more centra.

The hyoid cornu (*c.hy.*) is an obliquely oblong, massive plate of cartilage, somewhat twisted and strongly ridged below for muscular attachment. The antero-superior angle has been formed into an oval, gently convex condyle; the hinder corner is produced upwards into a large snag. Below, it is pedate, the sharp and somewhat upturned *toe* looking forwards. The hinder margin of the plate is gently concave, and the fore edge is sinuous.

The form of the still distinct ear-capsule is now that of a badly-shaped egg, with the broad end foremost; above, the cartilage is imperfect; below, it is becoming membranous at one point, although well chondrified on the whole.

This imperfect space is near the front and outer margin, a little behind the elbow of the mandibular pedicle; in it the cartilage-cells are being sundered, and the vacant place, the beginning of the "fenestra ovalis," is filled in with gelatinous tissue *. From this scooped space, backwards, the capsule is bevelled towards the edge; that projecting edge is the "tegmen tympani." Both the 5th and 7th nerves make their escape over the interspace between the pedicle and the auditory capsule.

Skull of Bufo vulgaris.—*Third Stage. Tadpoles* $5\frac{1}{2}$ *lines long.*

With but little increase in the entire length of the larva in this stage, the size and development of the head is remarkable. Most of the description of the last is applicable to this stage; but I here display the pattern of the Tadpole Toad's skull, as seen from above, with the hyoid cornua, the free mandibles, and the labials not drawn (Plate 55. fig. 3). One thing of great importance strikes the eye at once; this is the projection of the parachordal cartilage (*iv.*) in front of the auditory capsule. Now, in the Salmon ("Salmon's Skull," plate ii. fig. 5, *iv.*, *tr.*) the free ends of the parachordal bands, or "investing mass," look a little inward; but in the Fowl (HUXLEY, Elem. Comp. Anat. p. 138, fig. 57, F; "Fowl's Skull," plate lxxxi. fig. 2, *lg.*) the terminal part of each of these plates looks outwards and is abruptly truncated.

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* When the Tadpole is twice the size of this stage, viz. five sixths of an inch, then the gelatinous plug will be an oval plate of cartilage—the "stapes." My early observations on its formation were faulty; Professor Huxley pointed that out to me. We agree now as to the manner in which this plate is formed.

A line drawn, on each side, obliquely from the front of these processes to near the apex of the notochord (fig. 3, *nc.*) would be the true land-mark separating the trabeculæ from these hinder bands. The pyriform pituitary space (*pt.s.*) is now seen to have a low, but sharp wall enclosing it, on this side and on that. This wall is a crest growing upwards from the trabecula, and is the simple rudiment of the anterior and posterior sphenoidal wings and ethmoid, in one. Where these crests begin to die out, in front, there we see a cartilaginous bud on each side of the beginning of the internasal commissure. This is the first upgrowth of the prefrontal mass or lateral ethmoid. Afterwards (see "Frog's Skull," plate v. fig. 3) these buds will coalesce with each other and with the lateral crests, so as to form the round fore end and straight sides of the growing cranial trough.

Opposite these buds, above where the concave facet for the hyoid is formed, the mandibular pier is bent inwards, and from this concave margin there has arisen a large triangular, sessile leaf of cartilage (*or.p.*), which is *decurrent*, for it runs backwards along the mandibular stalk, cresting its outer edge. This sessile, broad-based leaf is apiculate, and the apex of it has coalesced with the trabecula, just outside the ethmoidal *bud*. This is the "orbitar process," which arches over the temporal muscle.

In the Common Frog ("Frog's Skull," plates v. & vi.), the Bull-frog, the Paradoxical Frog, and the Aglossal Toads (*infra*) this perfect arching over does not take place*.

At present the internasal plate (*i.n.p*) is only half as long as the free cornua (*c.tr.*); in front, where the curved bars lie back to back, it has their thickness, but behind it is bevelled; and this thin-edged plate is the commencement of a most extensive commissure, which will in time, when the larva is perfect, fill in the whole of the pituitary space, as in Sharks and Rays. One measure of the extent of metamorphosis undergone by these Batrachians can now be given. By my study of the huge Tadpoles of *Rana pipiens* and *Pseudis paradoxa*†, I learn that the projection from the outer side of the cornu trabeculæ, which gives attachment to the inner end of the "prenarial ligament" (*p.n.l.*), is the rudiment of the "alinasal floor," which projects outwards in a *cervicorn* manner (Plate 54. figs. 3 & 4) in the adult.

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* Professor HUXLEY informed me (summer of 1874), after showing me this perfect arch in Tadpoles of the Toad I had supplied him with, that he had found, from the distribution of the facial nerves, that the so-called "palato-pterygoid" of the Lamprey (see HUXLEY, Elem. Comp. Anat. p. 193, fig. 76, *e.*) really corresponds with the *external* orbital arch, and not with the true palato-pterygoid. This *petromyzine* structure, and the segmentation of the true palato-pterygoid arcade, make the skull of the Common Toad an object of great interest; further research amongst the "Bufonidæ" is also suggested.

† To be given in my next communication.

From this point to the posterior edge of the pterygo-palatine bar is the nasal region, and, with the help of the upper labials, this tract grows up into all that labyrinth. The trabecular cornua in front of that process grow, indeed, as long as the larva is a larva, and afterwards give off the "prorhinals" (Plate 54. figs. 3, 4, *c.tr.*).

The prenarial ligament in the Tadpole binds together the rudimentary *alinasal floor* and the inner face of the quadrate (*q.*); the corresponding point of the quadrate in the adult is exactly opposite the anterior margin of the exoccipital bone, which corresponds with a line drawn across through the middle of the cranial notochord*.

The auditory sacs (Plate 55. fig. 3, *au.*) are now obliquely pyriform; the cartilaginous coat, stretched almost to bursting by the rapid growth of the labyrinth, has yielded to the form of that which it bears within. An elegant, large, oval fenestra still exists on the top of the capsule, towards its inner side. This is the counterpart of the membranous space which lingers for some time in the roof of the capsule in the embryo of the Salmon ("Salmon's Skull," plates i., ii., iii., *au.*); this is the remains of the "aqueduct" or primary involution of the ear-sac (see "Pig's Skull," p. 299, plates xxviii. & xxix.). The huge semicircular canals shine through the hyaline cartilage and their fenestral membrane (fig. 3).

Skull of Bufo vulgaris.—*Fourth Stage. Tadpoles* 8 *lines long.*

In Tadpoles twice the length of the first stage here given, viz. two thirds of an inch long, I obtain a view of the substance, now considerably differentiated, which becomes the *stapes*. Professor Huxley had suggested that my first view ("Frog's Skull," p. 157) was incorrect, and that it was not *segmented out* from the already cartilaginous capsule, but formed later, by chondrification of the tissue lying in the fossa or primitive "fenestra ovalis" (see fig. 4, *f.s.o.*). I had long before found a *cleft* in the floor of the capsule in ripe embryos of *Salamandra maculosa*, and it seemed to me that this cleft went on to *cut out*, as it were, a large "bung." This process does take place in the "Urodela" (*Siredon*, *Salamandra*), but not in the "Anura." The pitting of the sac, below, in Toad Tadpoles 5 lines long (fig. 4, *au.*), is the commencement of a peculiar involution and subsequent rupture of the cartilaginous wall (fig. 5, *au.*, *st.*). By the huge, growing anterior and horizontal semicircular canals, and the development of the "tegmen tympani," the little pit is brought more beneath the capsule; it has also grown backwards, as a cleft, absolutely as well as relatively. The involution of the periotic wall appears as though it had been made by pushing in with a finger, obliquely, and the size of the opening is much less than it appears from the surface. It is an obliquely pyriform space, looking inwards, and extending its narrow end backwards; as is the

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* For the further development of the nasal labyrinth in the Batrachian, I must refer the reader to my former paper on the Frog, remarking that the part in the newly metamorphosed Frog (plate vii. fig. 11) does not show either the "labials" or the prorhinals. In the "Aglossa" I shall presently show very simple conditions of the labyrinth; but the most perfect elucidation will be given when I come to the Paradoxical and Bull-frogs.

shape of the fenestra, so is that of the *plug* which fills it (*st.*). The tissue of the walls of the capsule have long been hyaline cartilage (see figs. 1, 2, 3, *au.*); the plug (figs. 5 & 5^a, *st.*) is still composed of granular *indifferent tissue*, very consistent, but not cartilaginous; it *will be* cartilage when the Tadpole is the tenth of an inch longer, or in two or three days; for in Tadpoles one third longer than this stage (1 inch long) it is very solid cartilage. In seeking to settle the dispute as to the nature of this plug, it may be remarked that it lies at the bottom of the periotic fossa, and that its outer surface is scarcely flush with the periotic wall around it, and that its inner face is in immediate contact with the membranous labyrinth. Now the upper segment of the "columella," which is chondrified two months or more afterwards, does fit into the depressed part or fossa (see "Frog's Skull," plate vii. fig. 16, and plate viii. fig. 9); the interstapedial segment (*it.st.*) lies in the fore part of the *stapedial fossa* (*st.f.*), but the stapes itself covers the fenestra ovalis. When it is removed, the otoconial masses (*ot.*) shine through the fenestra (*fs.o.*).

I shall next describe the tardy-growing antero-superior segment, which attaches itself to the periotic plug or stapes, and whilst homologous in its nature with the fish's "hyomandibular," becomes, by specializing change, in *time* and in *form*, the auditory columella of a high Amphibian *.

Skull of Bufo vulgaris.—*Fifth Stage. Young Toads* 5 *lines long.*

These observations have been made to show the relation of the first and second post-oral arches to each other and to the auditory sac. My results correspond exactly with what Professor Huxley obtained *first*, in observing *Rana temporaria*. Seen from within (Plate 55. figs. 6, 7), with the basis cranii somewhat tilted up, the ear-capsule is found to be quite confluent with the parachordal cartilage (*iv.*); and now the tegmen tympani (*t.ty.*) is very large, and under its shadow we see the large, oval, plano-convex stapes, fitting into the recess which is open at its fundus behind, as the fenestra ovalis. The vestibular floor is gently convex, and is of less extent than the upper surface of the capsule, where the semicircular canals are imbedded; it retires most laterally, on account of the tegmen, but in front also, where the pedicle of the mandible runs (*pd.*), and also behind, where the 9th and 10th nerves (9, 10) pass out. The pedicle is much narrower, and clings close to the fore face of the capsule, as it passes into the trabecula (*tr.*), beneath the 5th nerve (5). But if the upper part of the pedicle is thin and narrow, its lower part is thick and broad; and it is the great distinctness of this tract of cartilage, and the special facet or condyle upon it (*c.pd.*), which beguiled me in my early

* Whilst carefully expressing my indebtedness to Professor Huxley for taking up this subject, and seizing by instinct, as it were, upon the erroneous parts of my description, I yet hold, most tenaciously, to my old view as to the homologies of the parts; namely, that the "stapes" is a *periotic*, and the whole, complex "columella" a *hyoidean* element. The fact that the stapes is formed out of the already chondrified periotic wall in the "Urodela," as is most plainly seen in young Axolotls 2¼ inches long, settles the stapedian homology; that the columella of the Batrachia is the homologue of the hyomandibular of *Proteus*, I have not the shadow of a doubt.

studies of the metamorphosing Tadpole (see "Frog's Skull," plate vii. figs. 1–5, and plate viii. figs. 1–4, *i.hm.*—"infra-hyomandibular," the erroneous name I gave to it). Even the fact that this tract was ossified by a bony plate (in the Common Frog and Bull-frog), which I correctly designated as the "metapterygoid," did not undeceive me.

In the third stage (fig. 3) the elbow of the mandibular pier is quite free from any otic attachment; but in larval forms of several kinds of Batrachia I have found *two* distinct binders, attaching these two unrelated parts together. In Tadpoles of the Frog an inch or more in length, and with hind legs apparent, there is a band which runs from the elbow, and then becomes pedate, attaching itself to the edge of the *tegmen* in front ("Frog's Skull," plates v. vi. vii., *s.hm.*). This part becomes detached as a small trefoil of cartilage; it lies *outside* the "portio dura," and becomes the "annulus tympanus." The next attachment is by a much larger band, the "otic process" of the mandibular pier ("Frog's Skull," plate viii. figs. 3, 4, *m.pg.*); in a further stage (fig. 8) it lies above *m.pg.* and *i.hm.*

In the Toad in this and the next stage it is seen outside the pedicle (fig. 8, *ot.p.*); it has coalesced with the anterior edge of the tegmen, and is invested with the squamosal: in the figure, being on the outside, much of the breadth is hidden.

The rest of the pier is now at right angles with the axis of the skull, and forms a large angle with the metapterygoid step on the pedicle: this is the quadrate region: its lower surface is obliquely scooped for the sinuous articular part of the free bar (fig. 6, *mk.*). The pterygoid bar (*pg.*) passes off at right angles with the quadrate, by a broad base in front of the meeting of the quadrate and metapterygoid regions; a bony ectosteal plate is forming on it, which runs forwards, and will spread upwards and downwards. Here we miss that other ectosteal plate which the Frog possesses, namely, the metapterygoid ("Frog's Skull," plate viii. figs. 4 & 8; it is lettered *m.pg.*, although attached to *i.hm.*).

The hyoid bar (*c.hy.*) was seen in the larva (figs. 2, 4) neatly articulated to the mandibular pier below the outer edge, and a little behind (=above) the outer or pterygoid end of the pterygo-palatine bar. Now that the quadrate condyle is opposite the optic foramen, instead of being opposite the nasal passage, the hyoid has had to go backwards with it. By such a change of position it has come very near to the fore margin of the auditory capsule, within easy reach of its external and lower edge, its ultimate destination (see Plate 54. figs. 4 & 7). This plate has become a narrow bar; it has become sundered from its neat joint, and its little rounded inturned condyle is now rather loosely attached by ligament; yet it retains, very nearly, its old attachment as to the *region* of the mandibular pier, which was, from the first, a little behind, or *above*, the root of the pterygoid.

The large, oval, externally convex stapes (*st.*) is nearer the posterior margin of the capsule than the anterior; its front end is a considerable way behind the condyle of the "pedicle;" it is attached to the outer face of the periotic capsule, under a large crescentic eave of cartilage—the *tegmen*. Only the hinder part of this plug has its inner face in contact with the membranous labyrinth, and that part is covered, outside, with muscular fibres (*m.*). All the fore part of the primary dint (fig. 4, *au.*) is floored with cartilage in front of the fenestra ovalis, and that part of the stapes which fits into this *closed fossa* is invested, on its outside, with a tissue that I failed to make out in my earlier researches. This tissue is a soft mass of fusiform cells, and is in shape like a half-opened fan, the sharp handle of which is twisted a little, and finds its way behind, and a little *outside* the pedicle of the condyle (figs. 6, 7, *c.pd.*, *co.*). This soft tissue fills in the inverted fossa beneath the fore part of the tegmen; it fines away to a point in front, but is copious where it lies in front of, and begins to invest, the stapes.

I do not suppose that the whole of this tract chondrifies; there is more of it than is wanted to form such a "columella," as we shall see in the next stage (fig. 8, *co.*). My view is that a filiform "core" of cartilage-cells is developed within this mass of tissue, and that the last is formed into fibrous connective tissue, the outer part of which is loose, and that further inwards more dense, forming the perichondrium of the slender rod.

Skull of Bufo vulgaris.—*Sixth Stage. First Summer Toads,* 8 *lines long.*

The figure here given is carefully drawn from my own preparation; but I had previously supplied Professor HUXLEY with numbers of young common Frogs of the same stage, and my first view of the first stage of a chondrified columella was from his preparations made from the Frogs. The drawings in his possession (made by him) differ in no way from these newer figures made by me; *newer*, however, by merely a few weeks.

The quadrate, with its obliquely scooped condyle, turns further backwards than in the last stage, the pterygoid ectostosis is spreading further up and down, and the hyoid is nearly touched by the leafy tegmen tympani (Plate 55. fig. 8, *q.*, *pg.*, *c.hy.*, *t.ty.*).

The arcuate "annulus" (*a.t.*) is seen, partly, through the chink between the hyoid and quadrate.

The stapes has now acquired its permanent shape (Plate 55. fig. 8, *st.*, and Plate 54. figs. 7 & 8, *st.*). Its otherwise regularly oval form is spoiled by a slightly concave emargination outside its fore end; against this emargination there lies the bulbous end of a small styloid cartilage. This rod is gently arcuate, and its convex margin is on the inside; it lies in an extension of the primary *inverted fossa* (see Second Stage, fig. 4, *au.*), which we saw began very near the mandibular "elbow," and then grew backwards. This style is the "columella" (*co.*); it fills the chink in front of the excavation of the stapes, a good distance from the fenestra ovalis, and growing forwards, turns outwards also, pricking its way by its delicate filiform end, between the tegmen and the condyle of the pedicle (*t.ty.*, *c.pd.*). It is evident, if we compare this rod with the perfect columella, that the extrastapedial plate and the suprastapedial rod (Plate 54. figs. 7, 8, *e.st.*, *s.st.*) have in this stage no existence; they are aftergrowths from the filiform end.

In our native Frog, by the first autumn the columella has become quite perfect ("Frog's Skull," plate viii. figs. 7, 8, 8^a, p. 172); not, however, in the manner of the Toad.

The points of importance in which the Toad's skull differs from the Frog's are the following:—

a. The "orbitar process" in the Tadpole forms a perfect arch over the temporal muscle.

b. The second upper labial coalesces in the adult with the internasal plate in front, and with the antorbital bar behind.

c. The palatine cartilage is segmented off both from the ethmoidal (palato-trabecular) and also from the pterygoid.

d. The upper part of the mandibular pier can be traced in the adult above the "condyle of the pedicle;" the stylo-hyal coalesces both with it and with the ear-sac.

e. There is no separate metapterygoid bone.

f. The columella does not subdivide its cartilaginous core; the subdivision here takes place far forwards, and not near the stapes, and is segmented, merely, as in Osseous Fishes, by separate bony shafts.

g. The extrastapedial is a large semioval leaf, and the suprastapedial *coalesces* with the "tegmen."

h. The hyoid bar coalesces with the periotic capsule.

i. The cartilaginous "annulus tympanus" forms only two thirds of a circle.

j. The common aliethmoidal, aliseptal, and alinasal roof is only one fourth the size.

k. The prorhinals or cornua trabecula are much smaller.

On the Skull of the Clawed Cape Toad (Dactylethra capensis, CUVIER).—*First Stage.*

For the skulls of the adult of this *aglossal* Toad I am indebted to Professor HUXLEY and Dr. DOBSON, of Netley; for the larval forms, in their various states, to Mr. T. J. MOORE, of Liverpool.

The young of this type was supposed by the late Dr. J. E. GRAY, F.R.S., to be a distinct species, and it was called by him *Silurana tropicalis* (Ann. & Mag. Nat. Hist. ser. 3, vol. xiv. p. 316, and Proc. Zool. Soc. Nov. 8, 1864, pp. 458–464). I have the satisfaction to find that Dr. GÜNTHER considers all these stages to be merely the changing forms of the ordinary Cape Toad. As to whether there is any real specific difference between *Dactylethra capensis*, CUV., *D. lævis*, GÜNTHER, and *D. Mülleri*, PETERS, does not affect this piece of research. The young specimens were brought by R. B. N. WALKER, Esq., from Lagos, and those dissected by me were taken from the same bottle as those described by Dr. GRAY (Proc. Zool. Soc. Nov. 8, 1864, p. 463, figs. 1, 2).

These marvellous siluriform larvæ appear to me to be equal in zoological and morphological value to any type whatever; to me their only rivals are the larvæ and young of *Pipa*, the other aglossal Toad.

The youngest of the larvæ brought home by Mr. WALKER are figured in full (Plate 56. figs. 1–3); these are much younger than the larvæ figured by Dr. GRAY (Proc. Zool. Soc. fig. 1). The outer form of the early stages of all the Vertebrata is of great importance to the morphologist, and also gives the zoologist a lively idea of the relation of the young of one kind to the adult of another.

In this type, also, I have had the advantage of fellow-working with Professor HUXLEY, who had made out much of the adult skull, carefully observing the nervous trunks, and who also examined the skull and cranial nerves of one or two small larvæ.

Help from such a quarter was of the utmost importance to me, and we both felt that we had to deal with a most difficult and enigmatical type.

The figures of early larvæ given in my former paper ("Frog's Skull," pl. iii.) do not show *the whole* of the creature; yet, as far as they go, they show how different our typical Batrachian larva is from that of the Cape Toad.

Equally important, both to Zoology and to Morphology, are the most patent differences: these are as follows, namely:—

a. The mouth is not inferior in position, suctorial, and small, but is very wide, like that of the "Siluroids" and *Lophius*; has an *underhung* lower jaw, an immensely long tentacle from each upper lip, and possesses no trace of the primordial *horny jaws* of the ordinary kind.

b. In conformity with these characters the head is extremely flat or depressed, instead of being high and thick.

c. There are no "claspers" beneath the chin ("Frog's Skull," pl. iii. figs. 10 & 11, *cp.*).

d. The branchial orifice is not confined to the *left* side, but exists also on the right (Huxley).

e. The tail, like the skull, is remarkably *chimæroid*; it terminates in a long, thin, pointed lash, and the whole caudal region is narrow and elongated as compared with that of our ordinary Batrachian larvæ.

f. The fore limbs are not hidden beneath the opercular fold.

To the anatomical reader I scarcely need explain the importance of these characters, especially that of the absence of the horny jaws; as it is at once seen that here this aglossal form agrees with most of the "Urodela," and that it helps to lessen the *reentering angle* between the diverging lines of those two amphibian groups, the Batrachia and the Urodela.

At present, in this the youngest larvæ, whose whole length is an inch and a quarter (three fifths of which is *caudal*), the fore and hind limbs are nearly equal in size (figs. 1 & 3); afterwards they show a different rate of growth; this is explained when we look at the disproportionate size of the hind limbs in the adult (Gray, *op. cit.* p. 461).

In seeking to decipher a chondrocranium like that of this stage of the Dactylethra's Tadpole, the earliest condition of such a skull, that is, as soon as this cartilage appears, must be held in mind. Now we have seen that such a simple framework can be made out, and that it differs but little in the Batrachia and Urodela (Plate 55. figs. 1, 2; and Huxley, "On *Menobranchus*," plate xxxi. figs. 1, 2). The points in which the two types differ are the early appearance of the bony plates in the Urodela; the absence in them, at this time at least, of a pterygo-palatine conjugation; the non-coalescence, at this early stage, of the pedicle of the mandible with the elbow of the trabeculæ; and the membranous condition of the fore part of the trabeculæ, namely, the internasal region and cornua. The hyoid is also longer, slenderer, and more loosely attached to the bar in front of it (HUXLEY, *op. cit.* fig. 2, *Hy*).

Now it may be safely taken for granted that the earliest chondrocranium of *Dactylethra* would exhibit all the essential Batrachian characters; and the condition here to be described in the earliest stage in my possession agrees with this assumption.

I shall therefore take the diagrammatic model or platform of the earliest chondrocranium of the Common Toad as the pattern of the foundation of this advanced chondrocranium of *Dactylethra* (see Plate 55. fig. 1).

For immediate comparison of a like stage to this, the reader is referred to the *third* stage of the Common Toad's Skull (Plate 55. fig. 3); the counterpart of this in the Common Frog is seen in Professor HUXLEY's last quoted paper (plate xxxi. fig. 3); the figures given in my former paper ("Frog's Skull," plate v.) correspond very exactly to the *second stage* of *Dactylethra* (Plate 57. figs. 1, 2). We shall need all these figures, and many more, for comparison; and when this most remarkable, flat chondrocranium is interpreted, it will serve as a key to unlock the mysteries of other remarkable chondrocrania, both of those which now exist, such as we see in *Chimæra* and the "Dipnoi," and of those that *did exist*, such as *Coccosteus* and *Pterichthys**.

Surely, in these latter, under the dermal scutes that are preserved there was a chondrocranium—the true endoskeletal skull—whose shape and whose morphological development must have answered, more or less closely, to that now under review, a *temporary* form and structure in this almost extinct kind of Toad.

The cranial structures in this Tadpole were much more flattened out than a side view of the creature itself (fig. 3) would indicate; for the outer skin is very loose, and the subcutaneous stroma is copious and extremely gelatinous. Unlike what we find in larvæ of the Common Frog and Toad, these Tadpoles are very delicately transparent, although richly supplied with brown pigment.

In this stage the occipital arch (Plate 56. fig. 4, *e.o.*) is imperfect above in the hind skull, and in front the internasal plate (*i.n.l.*) is flat, or rather subconcave, for the ethmoidal wall (see "Frog's Skull," plate v. *eth.*) has not yet been built. At present, then, we have a common cranio-nasal valley, whose bottom is formed behind of the parachordal cartilage and notochord (*iv.*, *nc.*), and in front, for twice the extent, of the trabeculæ, to whose extended edge in the frontal wall a long *labial* has been attached.

Laterally, the union of the parachordal bands with the auditory capsules (*iv.*, *au.*) has taken place very early; and with the antero-internal angle of each of these the trabeculæ are united, as well as with both the parachordals. The sides of the cranial valley are soon embanked into a narrow space by convergence of the trabecular elevations. There, at the narrowest, the brain ends, and the olfactory crura (1, indicated by a dotted line) are as long as the brain. Outside the wide *precerebral* valley we see the mandibular arch (*pd.*, *q.*), to which is attached the hyoid (*c.hy.*), and outside the mandibular pedicle

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* Note in HUGH MILLER's 'Old Red Sandstone,' plates i., ii., iii. & xi. pp. 72, 76, 78, & 279; and HUXLEY, 'Memoirs of the Geological Survey,' 10th Decade, 1861, p. 30, fig. xix.

(*pd.*) a large sinuous flap of cartilage growing from the front and side of the auditory capsule, and ending in a free "foot" (*t.*, *ty.*, *a.t.*).

All these parts have now to be described in detail. They are:—1, parachordal; 2, trabecular; 3, mandibular; 4, hyoid; 5, auditory; and 6, labial.

The branchial arches will be described in the next stage.

1. The parachordal bands enclose a large, long cone of notochord, with a rounded end, which is opposite the middle of the anterior semicircular canal (*a.s.c.*). It has retreated considerably. Tracing the grooved tracts of newer cartilage, we see where these bands have united with the large auditory capsules (*au.*), but not where they have passed into the *older* trabecular tracts (figs. 4, 5, *iv.*, *au.*, *tr.*). Below, the parachordals form a flap-shaped investment of the sides of the notochord; and they expand to reach the auditory capsules, where the 9th and 10th nerves pass out (9, 10).

Owing to the bulging of those capsules, these bands are pinched in the middle, and then they expand in front, where they are lost in the continuous mandibular and trabecular plates. Above, the parachordals are growing upwards, but they do not yet form a ring (fig. 4, *e.o.*). In front of the notochord and its investment, looking especially at the lower view (fig. 5), we see the cartilaginous floor growing forwards and outwards as *five* diverse leaves. The middle "leaf" is formed of *two* that have coalesced by their inner edges; these are—

2. The "trabeculæ," the first parts to chondrify. These confluent leafy bands extend from the notochord (*nc.*) to the great, transverse, "upper labial" (*u.l.*), fore and aft, and to athwart the "subocular fenestræ" (*s.o.f.*) and pterygo-palatine plates (*p.pg.*) on either side. They are more thoroughly seen above (fig. 4) than below (fig. 5). This is on account of the somewhat lower position of the mandibular pedicle (*pd.*). Most of the median part is *commissural*, having been formed, later than the primary bars, beneath the huge pituitary space (see Plate 55. fig. 1). The actual *relative* width of the primary bars can still be seen where the "cornua" curve round in front of the nasal sac (*e.n.*, *i.n.*), and behind the upper labial (*u.l.*). Hence we may infer that the large, gently concavo-convex plate (seen best below, on its *convex* face), up to the nasal sacs, is most of it the newer cartilage of the pituitary floor. On the sides, looking at the under surface (fig. 5), the trabecular boundaries of the old pituitary space have become leafy and hollow, elegantly, with an arcuate margin, widening up to their union with the pterygo-palatine bars (*p.pg.*). There they have become thick, and then, opposite their internasal region, they give off a pair of arms, like the arms of a sign-post. These arms (*p.pg.*) end in the quadrate condyle (figs. 4 & 5, *q.*), which scarcely projects beyond the pterygo-palatine (compare Plates 55 & 56).

From above we see that where the trabecular thickenings end there the banks of the median valley are not erect, but overhanging; so that, in front, the cranial sac is somewhat enroofed with cartilage; but all in front of that cavity, up to the nasal sacs (*i.n.*), is the ethmoidal region, which is almost as long as the cerebral. The ethmoidal part of the valley is now filled with a watery tissue; but in the next stage (Plate 57. fig. 1) it will be filled in with cartilage—two tubes, like drain-pipes, allowing the exit of the olfactory crura (1). Massive as the trabeculæ seem, as seen from above (fig. 4), from below (fig. 5), the interorbital margins (the eye, *e*, is seen to be indicated by a dotted outline) are merely thin, arched leaves of cartilage.

Besides the straight "arms" (*p.pg.*) which pass from the trabeculæ to the quadrate condyles, another pair of curved arms, in front of these, unite the trabeculæ with the distal part of the mandibular piers. These are the middle pair of transverse arms, or wings, growing from the front of this remarkable chondrocranium. In our native Batrachia the trabecular cornua (in the *tongued* types generally) are gently bowed outwards (Plate 55. fig. 4, *c.tr.*); but in the "Aglossa," as in the Sauropsida and Mammalia, they turn backwards, or, rather, they retain the retral condition they acquired during the "mesocephalic flexure."

Here, breaking free from the closely cleaving labial band (*u.l.*), on each side, the "cornu trabeculæ" (*c.tr.*) is seen to run outwards and then backwards, shutting in the nasal passage (*i.n.*), and losing its free end in the pterygo-palatine plate behind (*p.pg.*), and in the quadrate in front (*q.*). In this case the end of the cornu and the tooth-like process at its side which gave attachment to the "prenarial ligament" in the Toad (Plate 55. fig. 4, *p.n.l.*) have grown into one flat plate, and their cartilaginous substance has converted the ligament into a *lamina* (figs. 4 & 5, *p.n.l.*). Inside the condyle of the quadrate (*q.*) a toothed process is seen; this is for the insertion of the quadrate end of the ligament now chondrified. In *Pseudis paradoxa* the cartilaginous process from the quadrate runs across to the trabecula, but does not coalesce with it; in *Rana pipiens* the tooth is short, and from it the ligament passes to the even outer edge of the trabecula; in *Bufo vulgaris* (Plate 55. fig. 4, *tr.*, *p.n.l.*) the *tooth* is on the trabecula, and not on the quadrate.

3. The mandibular arch.

The origin of the next arch is best seen from below (fig. 5, *pd.*); and although the dorsal end of the mandibular arch is not equal to the trabecula, it is of great width. It runs winding itself in between the basis cranii and ear-capsule. On the whole, it lies, from end to end, on a lower plane than the inner arch; but even the quadrate, with its condyle on the antero-superior face, looks, in a bird's-eye view, to be nearly as high as the upper labial and cornu trabeculæ.

We miss here that elbow of the pedicle seen in the sigmoid mandibular pier of the ordinary Tadpole (Plate 55. fig. 4); for the bar runs forwards and outwards, almost straight, to the orbitar process (fig. 4, *or.p.*); between that and the pedicle it has lessened in width. It attains its greatest width where the elegant orbitar process grows out. This process, like a sessile leaf, is not sensibly *decurrent* along the outer edge of the bar, yet its base is broad. Quite normally, the edge of the base of that process is concave, for beneath it (fig. 5, *hy.c.*) is the hyoidean facet, a crescentic scooping away of the substance of the bar. The bar is also scooped into another elegant hollow on its upper face at the end of the fixed part (*q.*). This convexo-concave facet is for the articular end of the free mandible (fig. 6, *mk.*; it is here drawn separately with the hyoid to lessen the complexity of the main figure). Giving off two spurs to coalesce with the trabecula, the "prenarial" and the pterygo-palatine, the quadrate is of great breadth at this part.

Behind the pterygo-palatine bar, and between the trabecula and pedicle, we have a falcate membranous space, the "subocular fenestra" (*so.f.*); it is rounded in front, and its sharp end runs inwards behind. The eyeball (*e*) rests somewhat outside this space, on the mandibular pier.

The free mandible (fig. 6, *mk.*) is extremely small as compared with the hyoid (*c.hy.*); in the adult the mandible is much the larger of the two. At this stage the mandible is very long as compared with that of a common Tadpole (Plate 55. fig. 4, *mk.*), their mouths being so different. It is a slender, terete, sigmoid rod; the distal end is pointed and the articular end dilated. The articular and angular parts are curious; the former is not a notch nor the latter a spur, but the dilated end is excavated above, and surrounded by a ridge below. The points of the mandibular rods do not meet, but they are connected together by the interposition of a pair of short, terete, inferior labials (*l.l.*), which differ from those of the Frog's tadpole ("Frog's Skull," plate v. *l.l.*), for they do not *dip* into a steep "mentum," but lie almost on the same plane as the Meckelian rods. Their position may be understood by reference to the full figures (1–3), where it is seen that the lower jaw and lip point forward a little beyond the upper lip.

4. The hyoid arch.—Here there is nothing at present but the homologue of the infero-posterior piece of an Osseous Fish's embryo, the cerato-hyal (*c.hy.*), with no distinction of stylo-hyal above or of hypo-hyal below, and no inter-hyal placed between it and the mandibular pier. This huge, broad, solid bar (fig. 6, *c.hy.*) is typically Batrachian, with its rounded condyle on the antero-superior angle, its produced postero-superior angle, and its broad, pedate base. The sigmoid hinder margin is scooped on the inner side, and the outer side is ridgy.

The narrow helve of a thick-bladed trowel of cartilage separates and unites the hyoid cornua. The solid blade is lozenge-shaped; it is the 1st basibranchial (*b.br.*). The helve is the continuous basihyal (*b.h.*). In the Common Frog (*op. cit.* plate v. fig. 5) the basihyal is a small, distinct nucleus: the difference is, a little more differentiation in the common type.

5. The auditory capsules.—These "paraneurals" are so remarkably modified by cartilaginous outgrowths that they present no easy problem to one coming to them fresh from the common kinds. As in the fourth stage of the Toad (Plate 55. fig. 5), the fenestra ovalis is opening, but is only filled with indifferent tissue (Plate 56. fig. 5, *fs.o.*). Behind and mesiad of that fossa the sacculus is marked out as a lesser oval within the large oval of the capsule. Above (fig. 4), the semicircular canals (see, also, next stage, *a.s.c.*, *h.s.c.*, *p.s.c.*) are seen to be large, and shine through the translucent cartilage. The tegmen tympani (*t.ty.*) projects as a uniform lobe behind the capsule, then narrows to the middle, and then widens again. Now, however, it grows from the whole fore margin of the capsule, wedging

in and filling up all the space between it and the flat mandibular pedicle (*t.ty.*, *pd.*). Taking this antero-lateral start, it runs forwards, equal to the capsule in breadth and in length—a huge wavy ribbon of cartilage. In front it is not distinct, as cartilage, from a foot-shaped flap, which, added to it, almost doubles its length; for the *toe-end* nearly reaches the hyoid condyle (fig. 5), and overlaps the orbitar process (fig. 4). Just outside the front of the capsule the cartilage is punched, as it were, into a neat, round, nearly perfect hole, in which is imbedded a gland (? the "thyroid," *tr.g.*). This preauditory growth is the homologue of what I took to be the upper part of the hyomandibular ("Frog's Skull," plates v., vi., vii., *s.h.m.*). It behaves somewhat differently, however, for the anterior part does not coalesce with the mandibular pier, which, here, has no elbow; and the *foot part* answers to most of the little bar in the Common Frog. The broad proximal part is a huge awning to the *tegmen*, and the pedate part is the early condition of the *annulus*. The two parts show, *at present*, no sign of past or promise of future separation: they will separate, as we shall see (see Plate 58). Comparing these parts with what we see in the adult (Plate 59), with its huge columella with two bony shafts, ending in a huge heart-shaped leaf of cartilage, the extrastapedial, it seemed to me (and until the nerves were worked out by him, Professor HUXLEY sympathized with me in the matter) that here, if anywhere, we had the *supero-anterior* segment of the hyoid, the true hyomandibular, with its *symplectic* distal part.

The course of the "portio dura" beneath this awning directly contradicted this view, and a careful comparison of the various stages showed me how the pedate flap changed slowly into the cartilaginous tympanic ring. It became evident that, as in our native Batrachia, the "columella" is very tardy in development. I could not find it at all chondrified in the largest young (4th stage, Plate 58. figs. 2 & 3), although these were outwardly metamorphosed, save for the presence of a considerable tail (see Dr. GRAY'S illustration, Proc. Zool. Soc., Nov. 8, 1864, p. 463, fig. 2).

6. The labial cartilages.—In these, as in the other parts, the connecting-tracts have chondrified, and fused together parts morphologically diverse. Moreover, the right and left moieties have lost all distinction (Plate 56. figs. 4, 5, *u.l.*). This double labial (right and left in one) is equal in breadth and more than equal in transverse extent to the two cornua trabeculæ. Its fore edge is greatly concave; its hind edge is obliquely grafted on to the shelving fore edge of the internasal part of the trabeculæ; but a fissure appears on each side, and then the two bands diverge from each other (*u.l.*, *c.tr.*). Outside these is a sudden notch, but not an end to the labial; for this ribbon runs, as a gradually attenuating thread of true cartilage, to the very extremity of a long labial tentacle, so long at this stage that it reaches to the end of the abdominal cavity (figs. 1–3). This answers evidently to the persistent "maxillary tentacle" of the Siluroid fishes, e. g. *Clarias capensis*, *Arius rita*, &c.

I see no traces of any other tentacles than these. The Siluroids have two or three pair of them, or even more, the lower lip also possessing them. In *Dactylethra* the lower labials (fig. 6, *l.l.*) are smaller than in the common, and much smaller than in the Bull-frog.

The pointed end of MECKEL's cartilage is tied to the upper surface of the corresponding labial; this shows no tendency to become cirrose*.

On the Skull of Dactylethra.—*Second Stage. Tadpole* $1\frac{2}{3}$ *inch long.*

The skull of the next Tadpole is more than one third bigger, and the length is greater in proportion to the breadth; thus the large preauditory flap does not nearly reach the hyoid condyle. This relative, as well as real, elongation of the chondrocranium makes it less anomalous, and more easily comparable with that of the common kind.

Below (Plate 57. fig. 2), the cephalic part of the notochord (*nc.*) is less, and reaches a shorter distance between the auditory capsules. It is more completely embraced by the investing parachordals (*iv.*); where they clasp it behind there is on each side a gland, the "thymus" (*tm.g.*), close behind the double passage for the ninth and tenth nerves (9, 10). Above (fig. 1), the parachordals have united so as to form a superoccipital region (*s.o.*), which has a concave margin in front exactly over the end of the notochord. Where the parachordals are lost in the trabeculæ (fig. 2, *tr.*), there the gently convex cartilage is translucent enough to show the brain through it. Above (fig. 1), the brain is seen to be roofed over behind the optic lobes (C^2), this hides the medulla oblongata.

The sides of the "great fontanelle" are somewhat overhung behind by the auditory capsules, and in front by the ascending plate of the trabecula. The hemispheres ($C\,1^b$) show in front of them the olfactory lobes ($C\,1^a$), and from these the crura are seen, through the transparent cartilage, burrowing their way to the olfactory sacs (*ol.*). The median ethmoidal space is much denser, from the cranial cavity onwards; and a solid "mesethmoid" (*eth.*) is seen near the nasal organs (*ol.*) growing transversely to each hypertrophied trabecula, and forwards between the nasal sacs; this is the true perpendicular ethmoid, and when it has grown well forward, the fore part will be the septum nasi. Looking below (fig. 2) we see that the chondrified pituitary floor at the middle has become much narrower, and that from beneath the mid brain, halfway to the frontal wall, there is beneath a delicate style of bone, with a truncated hinder end; this *first bone* is the parasphenoid (*pa.s.*). Altogether the trabecular plates are narrower, although still convex above and concave below; the notch running from the subocular fenestra (*so.f.*) to the pedicle (*pd.*) is much more distinct. The trabecular plate is suddenly narrowed close to the nasal sacs below (fig. 2); here crescentic "subnasal alæ" (*sn.l.*), which converge towards the narrowest part of the internasal plate, bulge with the overlying nasal sacs (*ol.*). In front of these sacs the suddenly outturned cornua trabeculæ (continuous with the labial, *c.tr.*, *u.l.*) partly enclose the sacs by a tooth-like process; behind, on the front of the "palato-trabecular lamina" (antorbital), there is a similar tooth. Outside these teeth-like flaps is the internal nostril (*i.n.*); it is bounded within by these projections, and the nasal sac in front by the curving "cornu;" behind by the pterygo-palatine (*p.pg.*); and externally by the apex of the cornu, where it has coalesced with the quadrate, by the intermedium of the chondrified *prenarial* ligament. Below (fig. 2), it is easy to see that the upper labial (*u.l.*) is largely hidden by the underlying trabecular cornua; above, the reverse is the case, the labial tape being stitched on to the upper surface of the shelving frontal region of the trabeculæ. The conjugational plate (*p.pg.*) lies on a lower level than much of the trabecular band, above (fig. 1); it is, indeed, hollow above, in front of the fenestra (*so.f.*).

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* With regard to the probability of the existence of Teleostean fishes, related to the existing Siluroids, during the Devonian epoch (HUXLEY, Mem. Geol. Surv. Decade 10, p. 29) it may be suggested that the Siluroids now existing may be the specialized Teleostean representatives of truly *Ganoid* fishes, having a similar form, and existing in that early time. If so, we have three isomorphic groups of flat-headed Ichthyopsida, namely, such forms as the ancient *Pterichthys*, the modern *Clarias*, and the larval stage of this almost extinct kind of Toad (*Dactylethra*).

Also on a lower plane lie the ventral ends of the first arch, the mandibular, whose broad pedicle (*pd.*) runs into the trabecula behind its concave lower face (fig. 2). The notch between the first and second bar is rounded, and then, both having their contiguous edges convex, they come into contact for some distance, widening to form the fenestra (*so.f.*). All the landmarks round the pedicle are faintly visible, the intense chondrification having united this bar to the trabecula, the auditory capsule, and to the huge "tegmen" (*t.ty.*). Where the mandibular pier escapes, on the one hand from the tegmen and on the other from the trabecula, it runs as a broadish, straight band up to the hyoidean and "orbitar" expansions; the latter of these (*or.p.*) is less curved over the temporal muscle. From the quadrate condyle (*q.*), inwards, the common conjugational plate (*p.n.l.*, *p.pg.*) is of great breadth.

The free mandibles (*ar.*, *mk.*) are fast thickening, they are more arched, and the inferior labials (*l.l.*) are shown in their obliquity, dipping slightly into the gently convex *chin.*

The free hyoid arch (Plate 57. fig. 2, *c.hy.*, and Plate 58. fig. 1, *c.hy.*, *b.hy.*) is a solid, oblongo-arcuate bar, with ridges and sulci externally, for muscular attachment. The basihyal does not segment itself from the basibranchial (*b.hy.*, *b.br.*); they form one piece.

The branchial arches (Plate 58. fig. 1, *br.* 1–4) are a very remarkable structure; they are quite confluent with each other, opening freely within and without by three clefts. The first arch is a large bag of cartilage with thin, sinuous walls, through which are seen the radiating rows of *lophobranchiate* branchiæ. The second and third arches appear outside, as far as the clefts go, as moderately wide bars, but the fourth arch is a pouch, much less, however, than the first, and having its external face concave. Through the clefts can be seen the interdigitating hillocks of tissue from which the dendritic gills grow (see "Frog's Skull," p. 156).

On the edge of the upper lip a row of about twenty small teeth is seen, but the parostoses that are to form their foundation are not yet developed.

The auditory capsule is still unossified, the two sacs are more parallel than in the former stage, and the floor of the sacculus coming nearer to the outer edge, the now well-formed fenestra ovalis (*f.so.*) is almost vertical, on the outer wall, under the tegmen tympani. An oval, externally convex cartilaginous stapes (*st.*) is now formed. The tegmen is developed into a distinct "ear" behind, and helps to enclose the thymus gland (*tm.g.*); it is then narrow to the middle, and then suddenly spreads into the broad *awning*. Now may be noticed a better differentiation of these parts. The broad part of the tegmen in front, opposite the fore margin of the ear-capsule, is not punched out just at the edge, as in the last stage, but is snipped out twice as deep, so that the cut lip of the tegmen projects largely beyond the (? *thyroid*) gland.

Moreover there is now a good round notch on the fore margin of the flap of the tegmen, then a triangular tooth of cartilage, and outside, the long foot-shaped process, whose "heel" is now pointed. The broad, notched, outer part of the great flap of the tegmen is convex above and concave below, and so is the foot; between the two a more definite fossa has appeared, the commencement of a process which will pull asunder the outer piece, that it may become the Batrachian "annulus tympanicus," a part not *homologous* with the tympanic bone.

Skull of Dactylethra.—*Third Stage. Tadpoles at their largest size**.

The changes remarked in the last stage are still more noticeable in this; moreover there are several new structures. The fore face, in the first stage, was much the wider part. Now the greatest breadth is across the auditory region, if we include the *tegmina*. This is a steady growing towards that elbowing outwards of the auditory capsules which characterizes the skull of the adult Batrachian; and as the mandibular pier is attached to these masses, this their out-thrusting is a correlate of the immense gape ultimately possessed by all the members of this group, glossal or aglossal.

The much diminished notochord (Plate 57. figs. 3, 4, *nc.*) is now almost invested by the parachordals (*iv.*); it escapes behind between well-formed occipital condyles (*oc.c.*), and is most exposed above (fig. 3). In front it is hidden, below, by the haft of the dagger-shaped parasphenoid (fig. 4, *pa.s.*), which has now a "guard," giving its middle part a diamond shape. The foramen magnum (*f.m.*) is now neatly formed, and its sides in front of the rim are ossified, both by internal and external bony growth; these bones are the exoccipitals (*e.o.*); they leave, as they always will leave, an unossified upper and basal tract (*s.o.*, *e.o.*). Below, these bones are encircling the ninth and tenth nerves (9, 10); they then form a sickle, the concave edge of which is external, and the blade of which nearly reaches the mandibular pedicle (*pd.*). Now, if we refer to the ossified tracts in the chondrosteous skull of the Common Toad (Plate 54. fig. 4, *pro.*, *e.o.*), we shall see that the exoccipital only reaches, below, to the middle of the periotic capsule, and that its fore part is ossified by the prootic.

As in the larva of *Pseudis*, I note here, in *Dactylethra*, this generalized character, namely, that there is no fair landmark between these bones. From the auditory to the nasal sacs the floor of the skull is one wide sheet of cartilage (as in Sharks and Rays); it is gently convex in the middle, and concave submarginally (fig. 4, *tr.*). The sides are sinuous, and the greatest breadth is opposite to where the parasphenoid ends.

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* See Dr. GRAY's figure (1), Proc. Zool. Soc. Nov. 8, 1864, p. 463.

The subocular fenestra (*so.f.*) is narrower in front and wider behind; for now the pedicle (*pd.*) bends a little outwards, and its dorsal end can be better seen below, wedging itself in between the trabecula and the auditory capsule, and yet continuous with both. By their bending outwards we do get a very obtuse "elbow" to the mandibular pier, but this is masked by huge foregrowth of the tegmen (*t.ty.*).

The "orbitar process" (*or.p.*) is wasting, the articular pulley of the quadrate (*q.*) is now definitely seen in both the upper and lower view (figs. 3 & 4). Also, with greater clearness can we now see how the great labial adheres to the upper face of the internasal plate and cornua trabeculæ (*u.l.*, *i.n.l.*, *c.tr.*).

Small granular masses are forming around the nasal sacs, and are bearing new upper labials; there are two pairs above, and two pairs below (figs. 4 & 5, *u.l.*^{a}, *u.l.*^{b}, *u.l.*^{c}, *u.l.*^{d}). These cartilaginous nuclei will be described in the adult; the remarkable thing about them is that these *persistent* nostril-valves are not formed by the breaking up of the primary, upper labials (*u.l.*), and therefore they do not correspond with the two pair of persistent labials in the Common Frog and Toad (Plate 54).

The growth of the trabeculæ all about the nasal sacs is neater and fuller; the septum nasi (fig. 3) is now chondrified above, whilst its trabecular floor (fig. 4, *s.n.l.*) is narrower and longer. Besides this better setting of the nasal sacs, the cartilage along the huge ethmoidal region above (fig. 3, *eth.*), although translucent and showing the olfactory crura (1), yet is now solid. It is the extended counterpart of the little bowed wall of the Common Frog's Tadpole at the same stage ("Frog's Skull," plate v. fig. 3, *eth.* 1). The great fontanelle is exactly roofed over by a large pair of frontals (*f.*), which are gently convex, and together form an exact ellipse; stuck on to these, behind, are a very small pair of parietals (*p.*), sharp in front and broad behind; they overlap the frontals largely, and are just free behind. These, with the parasphenoid, are all the outer bony tracts I could find in this stage.

The large flap of the "tegmen" almost closes upon the thyroid gland (*tr.g.*), and the long outer lobe, broadening at each end, is becoming more evidently marked off from the tegmen, and more crescentic in form, ready to become the "annulus."

The tentacles (*tc.*) are one third shorter; altogether, this stage leads in gently towards the further metamorphosis of the large-legged Tadpole (Plate 58. figs. 2, 3).

Skull of Dactylethra.—*Fourth Stage. Young, with large legs and diminishing tail*[*].

The meaning of the lesser modifications in the last stage will be plain now that these parts are still more metamorphosed.

The breadth of the hinder half of the skull is twice that of the front half, and the auditory capsules and their curtains have added to them the projecting condyles of the quadrate, which in the first stage came up to the fore margin (Plate 56. figs. 4, 5, and Plate 58. figs. 2, 3, *q.*).

The foramen magnum (Plate 58. figs. 2, 3, *f.m.*) is now perfectly formed; the notochord (*nc.*) is much reduced, but can be clearly seen *on* the upper surface of the skull floor, and *through* the cartilaginous basioccipital region below. Between the occipital condyles (*oc.c.*), which look backwards and a little inwards, there is a deeper crescentic margination below, and a shallower above. Three fourths of the parachordal region, behind, and almost all the trabecular in front, is underspliced by a huge dagger of bone, the parasphenoid (*pa.s.*), which is rapidly acquiring its adult characters.

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[*] See Dr. Gray's fig. 2, *op. cit.*

But as at first (Plate 57. fig. 2, *pa.s.*), the hinder margin is still concave. The "guard" is a large lozenge of bone, with the hinder angle produced considerably and the front part greatly; this part, narrowing gently, runs up to the septum nasi, and there ends in a blunt point, which point is guarded by a transverse semicircular bone, the vomer (*v*).

The exoccipital bone (*e.o.*), which in the last had crept up to the parasphenoidal handle, has now crept over its edges, and has not only ossified the sides of the investing mass, keeping accurately to the boundaries of that part in front, but after hardening the submesial fossa it runs beneath the vestibule, so as to leave it only a selvage of cartilage. Behind, the bone runs to the margin of the capsule, enclosing the 9th and 10th nerves (fig. 3. 9, 10) in a double foramen; in front it just touches the point where the apices of the trabecula and mandible coalesce (fig. 3, *tr.*, *pd.*).

Above (fig. 2) the exoccipitals keep apart so as to leave a soft, square supraoccipital region (*s.o.*); behind it runs to the edge of the foramen magnum (*f.m.*); externally it reaches to the posterior canal, and runs forward over the edge of that and the anterior canal, at once fringing the canals outside, and the "fontanelle" towards the middle. This upper part ends, curving outwards, in front of the ampulla of the anterior canal. All this bony matter began in the occipital arch behind, and has grown into the substance of much cartilage above and below (Plate 57. figs. 3, 4, and Plate 58. figs. 2, 3, *e.o.*, *pro.*); it is a "prootico-exoccipital"—a double bony element.

The breadth of the great trabecular floor is not yet lessened, and it runs full in width up to the fore margin of the ethmo-palatine bridge (*e.pa.*), the front edge of which is semicircular, as the hind margin of the internal nostrils (*i.n.*). The projection inside this notch shows the breadth of the trabecula; there, however, it suddenly narrows in to form the subnasal laminæ, the moderately alate base of the septum nasi (figs. 2 & 3, *s.n.*). The septum above (fig. 2) has no larger aliseptals than the Common Toad (Plate 54. fig. 3, *al.s.*), but the subnasal plates are very small as compared with the common kind (Plate 54. fig. 4, and Plate 58. fig. 3). This deficient nasal floor is a curious arrest of the cartilage, which is so profuse immediately behind this part. The hurried retreat of the quadrate condyle (*q.*) has curiously affected the nasal labyrinth; the large flappy cornua trabeculæ (*c.tr.*) are now small crescentic wings, tilted in front of the nasal cavity. Where these are set on the septum (fig. 3, *s.n.*) is trilobate; the median lobe is the arrested rudiment (*pn.*) of the long "prenasal" of the Elasmobranch fish and the bird, and the paired lobes (*al.n.*) are the bud-like rudiments of the floor of the alæ nasi of the higher Vertebrata. The cornua trabeculæ (*c.tr.*) are curiously overlapped by the most highly developed form of nasal valve with which I am acquainted.

We saw that as we came up, step by step, the large labial ribbon became more distinct from the cornua trabeculæ. Now, in this stage, it has become two, and each moiety is also tilted up in front of the nasal cavity, like the trabecular cornu. Whilst the long tentacle has been diminishing this change has taken place, and it has become expanded into a pouch or "sling," which lies more over the upper than the lower surface. The point of this corded sling is the anterior valvular plate of the external nostril (*e.n.*), which in the Frog and Toad (Plate 54) was merely two thirds of each lateral labial piece. Besides these two there are three or four pair besides, as we saw in the third stage (Plate 57. fig. 4), but the third pair ($ul.^{c}$) escaped my observation in this stage; they are well seen in the adult (Plate 59)*. Above (fig. 2), there is one pair over the edges of the septum nasi and another pair attached to the valvular fold behind the outer nostril ($nl.^{a}$, $nl.^{b}$, *e.n.*). Below, the outer pair ($ul.^{d}$) lie in the folds that envalve the inner nostril (*i.n.*); these are large and somewhat trilobate: in the adult we shall see their homological meaning. Different as all this is from what takes place in the ordinary kinds, it is consonant with the generally unusual conditions of this type. The upper ethmoidal region (fig. 2, *eth.*) is still an unwonted structure. All the broad part of cartilage which extends from the frontal roof of the fontanelle (*f.*) to the nasal septum, merely corresponds, morphologically, with the cribriform plate and its cartilaginous setting in a young Mammal ("Pig's Skull," plate xxxiv. fig. 6, and plate xxxv. fig. 4, *cr.l.*, *al.e.*); and the pair of tubular passages, here, correspond to the many pairs of passages in the higher type.

The perpendicular ethmoid passes insensibly into the septum nasi now; the space between the olfactory crura (1) is much greater than the thickness of that partition wall. There comes out in this stage a process on the antorbital (palato-trabecular region), which is not definite in the earlier stages. In the Frog ("Frog's Skull," see plate v. fig. 3, and plate vi. fig. 3, *inside or.p.*) it helps the "orbitar process" to enclose the temporal muscle, but in the Toad (Plate 55. fig. 3) we saw that the two processes were united into a perfect bridge.

Since the last stage the condyle of the quadrate (*q.*) has retreated backwards a distance equal to one third the length of the entire skull; from being opposite the middle of the septum nasi, it is now opposite the fore margin of the frontal bone. Still being, like the trabeculæ, of great width, the intervening subocular fenestra (*so.f.*) is still a mere chink. Below (fig. 3, *pd.*), the pedicle is seen at its narrowest, where it is fused with the trabecula; from that point it spreads into a huge leaf of cartilage, which spreads outwards as far as the crescentic "annulus" (*a.t.*). But here we see that the once continuous cartilage in front of the auditory capsule has become divided into *three* distinct morphological structures.

The mandibular pier and the foliaceous tegmen (*t.ty.*) are quite sundered, and from the latter the annulus is detaching itself. The "elbow" of the mandibular pier, so striking a character in all the ordinary Batrachia, now, for the first time, is evident; it is no great distance behind the condyle, and runs by an almost transverse, sinuous edge into the pedicle, *beneath* the annulus. Above (fig. 2, *a.t.*, *pd.*, *q.*), that large cartilaginous crescent has pushed, as it were, the solid substance of the mandibular pier before it, as though it had been so much dough. The one has taken a visible impression of the other.

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* The third pair ($ul.^{c}$) are probably not distinct, but are the "prorhinal" growths of the trabeculæ.

Beneath the elbow the condyle for the hyoid (fig. 3) has become faint, for that bar (fig. 4, *c.hy.*) is loosening its attachment there. Over that, part of the orbitar process (*or.p.*) has been reduced to a sigmoid style, overlapping the angle of the pier.

The pterygo-palatine is no longer an extensive isthmus merely, which keeps the quadrate very close to the ethmoid; but added to that conjugational part is a retreating band, wide at first, but still steadily widening backwards, until it passes externally into the quadrate angle, and internally into the pedicle (*pd.*, *q.*). This newly developed tract is the pterygoid; for in the last stage the whole of the pterygo-palatine was merely an "ethmo-palatine," like a *secondary* conjugational band. A little crest of cartilage marks the point where the postpalatine passes into the pterygoid, and in front a prepalatine knob has appeared, which, below (fig. 3), has a thickened, condyloid appearance.

As a correlate of this retreat of the quadrate angle and trochlear facet, the mandible has grown largely (Plate 58. fig. 4, *ar.*, *mk.*), for the mouth is no longer *Siluroid*, but has become *Batrachian*. The whole arch is an elegant half-hoop; the articular end is very thick; and a uniform condyle projects from its upper surface, answering to the neat scooping on the angle of the quadrate. At the end of each Meckelian rod is the "inferior labial" (*l.l.*); and this, with its fellow, is more than ever in a line with the mandible itself. These labials help to form the "mentum;" they do not degenerate into fibrous tissue, or coalesce with the ventral end of the mandible, but become the "mento-Meckelian" element, in most Batrachia. But the adult shows no signs of them (fig. 6), nor has it any "mento-Meckelian" bone. In front of the mandible there is a small dentary, and below and within it a large *ectosteal* articulare (*d.*, *ar.*).

Notwithstanding that the stapes has been solid cartilage for the three last stages, there is, to me, no appearance of a chondrified columella, although I have sought for it with great care (Plate 57. figs. 2 & 4, and Plate 58. figs. 2, 3, *st.*).

And although the legs are large and strong, yet certain parts are but little metamorphosed at present. Thus the hyoid cornua (fig. 4. *c.hy.*) are now at their largest growth, although loosening themselves from their mandibular swinging point. What changes await these bars may be seen by comparing them in this fourth stage with those of the adult (fig. 5, *c.hy.*). They never reach higher towards the auditory sac than their counterparts in the "Urodela;" this is another peculiarity of this aglossal type. The basi-hyobranchial bar (*b.hy.*, *b.br.*) still retains its perfectly larval condition.

The auditory capsules, with their outgrowths, are mainly cartilaginous above (fig. 2), nearly the whole of the exquisite canals of the labyrinth being visible through the clear walls; they have ruled the outer form of the capsule. But that outer form is still further modified by the "awning," which is stretched out from their antero-external margin; this has changed greatly since the last stage (Plate 57. figs. 3, 4, *t.ty.*, *a.t.*). Nearly separated from the outer crescent, the true "tegmen," as seen from above (fig. 2, *t.ty.*), looks as if the valve of a leguminous fruit had grown obliquely from the capsule; and, indeed, this is its shape, for it is convex above and hollow below (figs. 2, 3).

The crescent itself (*a.t.*) seemed to me at one time to be the early condition of the "extrastapedial" of the adult (Plate 59, *e.st.*). Supposing the "tegmen" to be its stalk, and ready to ossify into the "medio-stapedial" and "interstapedial" shaft-bones, this heart-shaped leaf of cartilage, blade and petiole, seemed all ready to become the columella of the adult, and the homologue of the fish's hyomandibular and symplectic*.

The *thyroid gland* (fig. 3, *tr.g.*) lies now beneath the stalk and leaf of cartilage; I have indicated its position by dotted lines. The stapes (*st.*) has been teased away from the fenestra ovalis (*fs.o.*) to show its shape, it is irregularly oval and convexo-concave, and its outer convex surface is seen to be covered with muscular fibres.

The fossa (fig. 3), now fairly on the side of the auditory capsule, is only *open* behind; even the stapes itself is much larger than the fenestra, which is covered by its hinder half.

The new bones now apparent are the vomer, nasals, premaxillaries, maxillaries, dentaries, and articulars; the two latter have been described already. The vomer (fig. 3, *v.*) is semicircular, with the hinder, abrupt edge sinuous; it invests the apex of the huge parasphenoid (*pa.s.*). The maxillaries and premaxillaries (*mx.*, *px.*) form a crescentic row of bones outside the front of the face, and on their under surface we see the teeth. The maxillaries run scarcely twice the extent of the premaxillaries; the latter have already a nasal and a palatine process (figs. 2 & 3, *px.*).

The nasals (fig. 2, *n.*) are large, accurate crescents; they are margined with a flap of membrane on their concave or anterior margin, and this is further margined by a labial ($u.l.^{b}$); this complex nostril-cover is behind the external passage (*e.n.*). Altogether, this Toad has its breathing-passages protected by a most complex valvular apparatus.

The frontals (fig. 2, *f.*) have increased in size, and, save at the hinder margin, are well ankylosed together; the parietals (*p.*) are parasitic plates, overlapping the frontals.

By comparison of this half-metamorphosed young specimen with the adult, seeking side-lights from more familiar Batrachians, we shall be able now to appreciate the remainder of the metamorphic modifications, by which the skull of the Siluroid, and almost Chimæroid larva of *Dactylethra* passes into that of the adult. In its last stage we shall find as many notable things as in the larval; for this type is very contrary, not only to the common tongue-bearing types, but also to the other aglossal form, namely, *Pipa*.

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* The merciless rigour of my fellow-labourer Professor Huxley's criticism has been of the utmost value to me in this and in many other cases; and I am truly grateful for the effect upon me, of the wholesome incisiveness of his inborn, logical severity.

Skull of Dactylethra.—*Fifth Stage. The adult Toad* *.

The occipital condyles of *Dactylethra* are quite normal: they are principally seen on the upper surface (Plate 59. figs. 1, 2, 4, *oc.c.*), and they look only a little outwards, much of the cartilage lying towards the articular mid line. The foramen magnum (fig. 4, *f.m.*) is very large and steeply placed; it is squarish, the upper and lower margins being somewhat convex, and the lateral margin concave. A narrow tract of cartilage, above and below, separates the two great side bones, the exoccipitals (*e.o.*): these synchondroses are the super- and basioccipital regions (*s.o.*, *b.o.*). The chondrosteous cranium is overlapped almost to the end by the fronto-parietal slab (*f.p.*), and the basal region is only free at the very end from that long bony bulk, the parasphenoid (*pa.s.*).

A lobular process from each exoccipital mass arches over, on each side, the hind skull; these lobes are united into one roof by the superoccipital synchondrosis. Below (fig. 2), the exoccipital bony mass is flat on each side of the handle of the long parasphenoidal sword, behind. Then on each side where the handle narrows to the "guard," the sides of the skull-floor are largely scooped, which scooping is part of the huge *Eustachian vaults*; for here the first postoral cleft forms a large chamber on each side, the door of these chambers being common†.

Above, when the fronto-parietals have been removed (fig. 1), we see one large fontanelle (*fo.*) reaching from the occipital ring to the front of the cranial cavity. There are no subsidiary fontanelles as in the common kind (Plate 54. fig. 3). Nearly the whole of the side of this open roof is solid bone; and this side wall, in the wider fore part, thickens and shelves over the cranial cavity, in some degree. Below (fig. 2) the bony substance has crept nearly up to the nasal domes; and at the sides (fig. 3) to a short distance behind the "palato-trabecular junction." Nothing but cautious observation of many types and many stages will show what is the meaning of this abnormal girdle-bone, which is so unlike that of the Common Frog and Toad (Plate 54. figs. 3, 4; and "Frog's Skull," plate ix.).

Regionally, it corresponds with the whole sphenoidal territory of a Mammal ("Pig's Skull," plate xxxv. figs. 4, 5), and its fore edge does but reach the hinder margin of the ethmoidal territory. To what a narrow, transverse headland of cartilage this once huge territory is reduced, may be seen by comparing this with the early stages; here (figs. 1, 2, 5, *eth.*) its breadth is not greater than that of the fore part of the fontanelle. The kind of ossification here seen is that which is common in Batrachia when the chondrocranium becomes solid bone; the cartilage-cells first calcify, superficially, then true ostosis takes place in and among them, and, finally, the process reaches to the perichondrium; but there is no separate, preformed *ectosteal* lamina.

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* I have worked at the two skulls of the adult; one kindly lent me by Professor HUXLEY, after partial dissection by him; and the other by Dr. DOBSON, of Netley. For Professor HUXLEY's views as to the skull of *Dactylethra*, see his recent Article on the "Amphibia" in the Encyc. Brit. p. 755.

† "The Eustachian tubes [are] united into one pharyngeal orifice" (GRAY, "On *Dactylethra*," Proc. Zool. Soc., Nov. 8, 1864, p. 464).

There was, we saw, however, such a lamina, the first starting-point in the formation of the Frog's girdle-bone; and it existed when ossification of the actual cartilage had barely set in (see "Frog's Skull," plate viii. fig. 7, *eth.* p. 173, stage 9th). In that observation I was right as to the bone, but did not fully see that the ossification of the underlying cartilage right and left took place *independently* of, but in consonance with, this ectosteal "superethmoidal" plate. The fact is that the girdle-bone in the frog is formed in the same way as its "suprascapula," the outer and inner bony growths being, at first, quite independent of each other ("Shoulder-girdle and Sternum," plate v. var. figs., *s.sc.*, p. 79). In the common Toad and Frog this upper plate soon coalesces with the circle of bone which is formed around the ethmoidal region, changing the solid cartilage into dense bone (see "Frog's Skull," plate ix. var. figs., *eth.*).

In *Dactylethra* this does not take place; here (Plate 59. figs. 1 & 3, *s.eth.*) a large elegant "supraethmoidal" plate lies unattached on the surface of the unossified ethmoidal cincture, which in the frog is marked out by being bony, whilst in this type it is mapped out very exactly, behind, by the arrest of bony deposit, and in front by the presence of the nasal membranes. The overlying "supraethmoid" is a common bone among Ganoid and Teleostean Fishes ("Salmon's Skull," plate vii. fig. 1, *eth.*); it crops up again in Lizards and Struthious Birds. Its form, here, is triradiate—its fore ray being an oblong bar overlying the septum nasi, and the hinder part consisting of a pair of pointed wings.

When this bone has been removed (Plate 59. fig. 5) the ethmoidal region of the skull shows a transverse, serrated margin. The outer of these serrations are the short, prepalatine spikes (*pr.pa.*); the median projection is the perpendicular ethmoid overlying the grooved top of the septum nasi (*s.n.*); the intermediate serræ grow forwards from the broad junction of the antorbital projection of the ethmoid with the ethmo-palatine bar (*e.pa.*).

Below (fig. 6) the bone of the common sphenoidal trough reaches into the substance of the ethmoid, behind; but its fore part is soft; and an elegant crescentic thickened rim curves round behind the nasal pouches,—very *Selachian* pouches they are.

This rim reaches as far as the condyloid boss on the under face of the palatine, and the two thickenings together form a sigmoid structure. The postnasal rims pass into the narrow hinder part of the feebly alate base of the septum nasi (*s.n.*), which ends in front in three buds of cartilage; these are the rudiments of the azygous prenasal and the alæ nasi (*pn.*, *al.n.*). Above (fig. 5) the aliseptal laminæ are not more developed than the subnasal, below. They have clubbed ends, distinct from the alinasal rudiments.

The cornua trabeculæ (fig. 6, *c.tr.*) are extremely unlike those of the frog and toad (Plate 54); they are continuous with the great labial pouches in front (*u.l.*), and with the septum nasi in the middle. These cornua are not seen above (fig. 5), being covered by the labial pouch; but below they are seen, as in the last stage, to be tilted plates, with their convex face in front; they grow outwards and turn backwards, and help to give complexity to the infoldings of the Schneiderian membrane. The variously roofed nasal domes are like enough to those of a Skate or Shark below, and their valvular cartilages are homologous; but their roof is imperfect and, as becomes an air-breather, *perforate* (figs. 1, 3, 5, *e.n.*). Besides the investing bones to be described anon, there are three pairs of *labial* valvular cartilages above. The most notable pair look like leathern bottles, the neck of each looking inwards and forwards; but they are mere " slings " that have lost their " tentacular " cord (Plate 57. figs. 2 & 3, *u.l.*). Below (fig. 6) we see this, their lower edge being inturned only slightly. The inner end of these conchoidal cartilages is covered with a small spatulate separate piece (fig. 5, *ul.*^{a}), and as this is attached at right angles to the large labial a space is formed; this is the fore margin of the external nostril (*e.n.*). Its hind margin is formed of membrane, a large space existing where the aliseptals are so deficient; across the middle of this space, another labial, oblong, and twice the size of the last, runs inwards and forwards to the septum (fig. 5, *u.l.*^{b}). Below (fig. 6, *u.l.*^{c}) another pair of spatulate cartilages (" ? prorhinals ") are seen, near the septum, and having their " handles " looking backwards. Helping to close the open nasal space below (fig. 6, *u.l.*^{d}) the last pair of " upper labials " is seen. Each cartilage lies inside the arcuate rim, nearly touching the prepalatine by its outer end; it is a thick, short, arcuate, twisted bar of cartilage; this bar has its exact counterpart in the Shark.

Passing to the mandible and its outgrowths, we find characters very unlike those seen in the ordinary Batrachia. The pier of the mandible could be well traced in the last stage, with its flat pedicle and the elbowed rudiment of the otic process (Plate 58. fig. 3). The upper part of the pier is largely cartilaginous even now, but it is much hidden by a number of bony plates; whilst the quadrate region is converted into a true (*ichthyic*) quadrate bone (Plate 59. figs. 3, 4, 8, 9, *q.*). The metapterygoid region may be seen as a tract of cartilage in the front face of the pier of the mandible, where the long processes of the pterygoid and squamosal, and the shorter plate of the quadrato-jugal, have been cut away (Plate 59. fig. 9, *ot.p.*, *pd.*, *pro.*, *sq.*, *q.j.*, *q.*, *pg.*).

There is no metapterygoid bone covering the pedicle, but merely, as in *Bufo vulgaris*, a process of the pterygoid bone (*pg.*). Looking at the skull from behind (Plate 59. fig. 4), we see that there is a large synchondrosial tract connecting the prootico-exoccipital mass above and the quadrate below (*pro.*, *e.o.*, *q.*); this is the common territory of the tegmen tympani and " otic process " of the mandibular pier. This tract is also seen in the upper view (fig. 1), but there we only see the cartilaginous selvage which belongs to the " tegmen ; " the squamosal (*sq.*) covers the otic process. The backward extension of the quadrate angle and condyle is not equal to what is seen in the Frog and Toad (Plate 54. figs. 3 & 4); and we have here what is not seen in the common types, namely, a well-ossified *quadrate region*, as in the Osseous Fish (" Salmon's Skull," plate vi. figs. 1, 2, *q.*), and to a less degree in the " Urodela " (HUXLEY, " On *Menobranchus*," *op. cit.* plate xxx. fig. 1, *Qu.*). Here it is an obliquely oblong bone, oddly bent backwards from its metapterygoid cartilage above, and then having its base turned forwards again

(Plate 59. figs. 3 & 8, *q.*), quite unlike what we see in the common kinds. Again I must refer to the separated pier (fig. 9), seen as attached still to the prootic (*pro.*), but having all the projecting parts of the bones cut away, so as to clear the view. As in the side views (figs. 3 & 8, *q.*), the elegant quadrate *trochlea* has its fore part tilted up, and, lying round and above this articular region, we see a *squarish* quadrate bone (*q.*), with the external process of the pterygoid bone (*pg.*) clamping its inner face (see also fig. 2, *q.*, *pg.*). But above the square quadrate there is another bony plate (less square in form) grafted upon the cartilage also: this is the quadrato-jugal (*q.j.*, seen also in lateral view, fig. 8, *q.j.*). Over this is a third bone, only half as deep, and less strongly attached to the cartilage; this is the squamosal (*sq.*; see also fig. 8, *sq.*, where it is seen from the side).

The last bone, the squamosal, invests the otic process (*ot.p.*), whilst the pedicle (*pd.*) is the triangular tract of cartilage running from the outer to the inner side, where it is surmounted by the prootic (*pro.*) and supported by the pterygoid (*pg.*)*.

The general relations of the squamosal and quadrato-jugal will be considered with those of the other investing bones.

The ectosteal pterygoid (a huge bone) has eaten up all that cartilage which we saw in the last stage running from its broad root on the mandibular pier to the palatine region (Plate 58. figs. 2 & 3, *pg.*, *q.*). This bone, below (fig. 2), is gently convex throughout; its broad root is three-spurred: the inner and foremost of these spurs is a sharp, twisted style, which clamps the fore face of the prootic, external to the foramen ovale (*pro.*, 5, *pg.*). The outer spur is like unto it, but grows outwards and backwards in an exactly opposite direction, clamping the inner face of the quadrate, as we have just seen (fig. 9). The inner spur is an elegant, large, auriform lobe; it forms the outer solid floor of the tympano-Eustachian dome. Externally it lies under the ligamentous stylohyal (*st.h.*), hiding its attachment; internally, it gives off a strong fascia, which is attached to half of the transverse ridge that runs across the parasphenoid, in front of the "guard." Thus we see that the pterygoid binds beneath the skull from the mid line to the quadrate, and the huge Eustachian passages meet behind the pterygoid fascia, to open as one in the roof of the pharynx.

The stem of the pterygoid is first broad and then narrow. At first it elbows out towards the cheek, just catching the long squamosal spur; it then runs forwards and a little inwards, and is spliced on to the inner face of the postpalatine cartilage (*pt.pa.*). The pterygoid is distinct from the palatine—not, however, as in the Toad (Plate 54.

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* The Batrachia are constantly breaking down in the matter of *parostosis* and *ectostosis*, which are true enough as distinctions in the higher groups. In the outer views of the quadrato-jugal I have left the bone (*q.j.*) uncoloured; but the part grafted upon the ascending otic process of the quadrate (fig. 9) is coloured, because here it acts the part of an "ectosteal" plate. I now have the satisfaction to agree with Professor HUXLEY (art. "Amphibia," fig. 9, *Qu.J.*, p. 755) as to the proper homology of the styloid bone which is attached by its broad, hinder end to the quadrate in the Frog and Toad (Plate 54. fig. 7, *q.j.*). Its *ectosteal relation* to the quadrate cartilage in the common kinds was a stumbling-block to me, and in my former paper it is called the quadrate ("Frog's Skull," plate ix. *q.* & *qu.*). It is one of the common instances in this group of *one bone* taking the functional place of *two*.

figs. 3 & 4), by proper segmentation of the cartilage, but because the pterygoid cartilage is used up by the bone; whereas the palatine is quite unossified, it has no ectosteal bar, and merely shows some *calcification* where it is set on to the ethmoid (*e.pa.*). At present this is the only Batrachian in which I miss the ectosteal palatine bar.

The free mandible has an oblique, sinuously convex condyle, accurately surrounded by the articular bony plate (Plate 58. fig. 6, and Plate 59. fig. 3, *ar.*); this is the angular (*An.*) of HUXLEY. This bone has transformed most of the cartilage, but in front it breaks out again, and shows no distal ossicle ("mento-Meckelian"), but, reaching to near its end, and running along the outside as a spinous splint, we have the dentary (*d.*); it is two thirds the length of the mandible. On the inner side (Plate 58. fig. 6, *ar.*) the articular ends in a spike, at a small distance from the fibrous symphysis.

In the hyoid arch the *antero-superior* element has appeared, which we saw not in the last stage (Plate 58. fig. 3), only a cerato-hyal being there present; but the stapes already, for several stages, had been perfect.

If we creep along cautiously, without taking thought either for *function* or for what shall be seen in higher types, it will not be hard to find that here, late in life, has appeared the lacking upper segment of the "2nd postoral arch." Holding in mind what is familiar in the various groups of fishes, this new part may be considered as the homologue of the hyomandibular and symplectic of the Osseous Fish ("Salmon's Skull," var. loc., *h.m.*, *sy.*), the proximal bone being the hyomandibular, and the distal, with its free cartilaginous extremity, the symplectic*.

But I gladly use Professor HUXLEY'S *tympanic nomenclature* for this upper bar, this *hyostapedial* chain.

The "columella" of *Dactylethra* (Plate 59. figs. 1, 2, 3, 4, 7) is bufonine (see Plate 54. figs. 7 & 8), and does not agree with that of the Frogs ("Frog's Skull," plate viii. figs. 8 & 9). In the Toads there is no separation into two distinct segments of the primary cartilaginous bar (Plate 54. fig. 8, *co.*); but the more rounded proximal part, the *stalk*, is ossified as two separate shaft-bones, the proximal end of the proximal piece articulating with the stapes (fig. 7, *st.*).

The curve which has to be formed by the columella (figs. 1, 2, 3, 4), as it stands out from the stapes, which is set in the postero-superior face of the outspread ear-capsules, is evidently at the bottom of this peculiar segmentation.

The upper piece, or "interstapedial" (*it.st.*), is bent on itself; the second piece, or "mediostapedial" (*m.st.*), is bent on it; and this bar also is bent on itself, but gently, in an arcuate manner.

This curvature is still contained in the *leaf* (see from the inside, fig. 7, *e.st.*), which is applied over the outer face of the squamosal, quadrato-jugal, and quadrate, reaching further forwards than the fore margin of the foramen ovale (figs. 3, 5). The entire curvature of the columella is equal to a quadrant; it is, however, oblique, for the large outer face of the leafy extrastapedial is well seen in the upper view, and only partially on the lower (figs. 1 & 2, *e.st.*). Seen from within (fig. 7) the leaf seems to be *cordate*; but its lobes overlap the stalk (see fig. 1), and closely approach each other, except at the base.

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* If it be asked why the end of the symplectic passes *over* the quadrate, whereas it was *under* in the Osseous Fish, I answer that they are both *secondary* morphological positions; primarily they are *serially homologous*, and should (*and did*) simply lie in the same plane.

The extrastapedial of *Bufo vulgaris* (Plate 54. figs. 7, 8, *e.st.*) is small and inelegant compared to this, whose exemplar is the leaf of a water-lily. But the *setting* of this plate is equal to its *form*; around it is the attenuated *annulus tympanicus* (compare Plate 58. figs. 2 & 3, *a.ty.*, with Plate 59. figs. 1, 2, 3, 4, 7, *a.ty.*), whose upper deficiency, much less than in *Bufo*, is supplemented by two *true* tympanic bones, not *single*, as in the Mammal, but *divided*, as in the Bird (Plate 59. figs. 3, 7, 8, ty^a., ty^b.). The upper tympanic bone (fig. 3, ty^a.) lies on the junction of the medio- and interstapedial bars *.

The infero-posterior segment, or element of the second postoral arch, has dwindled to a mere tape (Plate 58. fig. 5, and Plate 59. figs. 2, 3, 4, *c.hy.*), whereas it was massive in the extreme (Plate 58. fig. 4, *c.hy.*). It does not reach the typical Batrachian place of suspension, namely, behind and below the otic process of the mandible, but is suspended thereto by a ligament, almost a quarter the length of the bar. This ascent of the cerato-hyal is about equal to that of a Urodele.

The cerato-hyal is but little wider in the middle; it is gently hooked round below, meeting its fellow at the basal bar. All these are nearly of the same breadth and strength; all are fused together, and the median part is still continuous with the basibranchial (*b.br.*). The anterior part of the barred branchial pouch (Plate 58. fig. 1) is converted into a persistent functionless branchial (Plate 58. fig. 5, *br.* 1, 2) of great length and breadth. The apiculate anterior part of the two bars is bound together by the confluent broad basibranchial (*b.br.*); then there is an oval fenestra, and behind this a small hypobranchial band passes inwards, on this side and on that, and from the confluence of these there grows a wider band, which speedily becomes trifid. These three processes grow directly backwards: the middle is short and unossified, an oval lobe; whilst the paired processes are the huge, long, little-diverging "thyro-hyals," the *representatives* of the cornua majora of the Mammal—not formed, as in that group, out of the first branchial arch, but rather being a modified condition of the hypobranchial region of the third and fourth. The larynx (*lx.*) lies between these bars, which have each an osseous shaft, as in the Frog ("Frog's Skull," plate x. figs. 1 & 2, pp. 171, 172)†.

Together, the external and internal auditory structures form a large, double labyrinth, with the narrow cranial tube between the right and left regions.

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* In the *inverted figure* (7) the whole columella is shown dislocated, to display its inner face, and drawn from under the upper tympanic.

† Professor Huxley contends with me as to the truth of this, remarking that the thyro-hyal structures are *median* in the Urodeles. They *are so* in them, and yet only submedian in the *Anura*; the changing of the distal part of a rod into a basal piece is a very simple and common process.

Below (fig. 2), but little is to be seen, for the floor of the vestibule forms the vaulted roof of the tympano-Eustachian cavities, and these are largely floored by the leafy pterygoid bones. Between the front and middle lobes of that bone the foramen ovale is seen (5)—a huge space when seen sideways (fig. 3). The thick, notched margin of this passage is formed, behind, by the prootic (*pro.*), and in front by the sphenoidal wall (*al.s.*), in which is seen the optic foramen (2), which shows where the orbito-sphenoidal region (*o.s.*) begins. The hinder part of the epiotic region (*ep.*) is seen roofing the double passage for the ninth and tenth nerves; from this part to the hind edge of the pterygoid the region is opisthotic.

Above (fig. 1), the elegance of the periotic masses appears; they form the massive piers of the occipital bridge, the keystone of whose arch is an oblong brick of solid cartilage (*s.o.*). But these periotic "piers" are of twice the extent of the arch, and they spread into rounded lobes far beyond the curving of the upper part, where the semicircular canals are imbedded. The carved work on the top varies; for whilst the anterior and horizontal canals (*a.s.c.*, *h.s.c.*) are simply rounded elevations, the posterior canal (*p.s.c.*) has a sharp (epiotic) crest growing from it, which looks backwards, and grows forwards and inwards.

In front of the anterior canal the prootic sends forwards and inwards a rounded lobe; this is separated by one rounded notch from the superoccipital and by another from another lobe. The inner lobe is separated by synchondrosis from the bony alisphenoidal wall (fig. 3, *al.s.*, *pro.*). The outer lobe is the front part of the tract that lies outside the horizontal canal, the "pterotic" region, which is concave close to the canal, then convex, and then, the bone ceasing, we have the "tegmen" running into the "otic process." This description of the upper view will be better understood if the eye is made familiar with the *side* and *end* views at the same time (figs. 3 & 4).

That part of the periotic mass which is directly connected with the *middle ear* is shown in a separate figure (fig. 7), more enlarged; it is inverted, and the columella carrying the stapes is drawn as dislocated and turned over. The squamosal and quadratojugal (*sq.*, *q.j.*; see also those parts not inverted in fig. 8) have the tympanic apparatus affixed to their outer surface, and the great extrastapedial leaf is imbedded in the fibrous "membrana tympani." Air finds its way between that leafy growth and the bones within, and can pass round the columella, through the opening (formed by the "annulus," the tympanics, squamosal, quadrato-jugal, quadrate, and a ligament, see fig. 8) into the vaulted tympano-Eustachian cavity. The fenestra ovalis marks the periotic regions, for that which surrounds it in front is the region of the prootic, that which is behind the opisthotic (fig. 7). The actual opening (fenestra ovalis) is a small funnel, lying at the inner and *hinder* extremity of an oval trough; the little, semiovoidal, cartilaginous stapes fits accurately into this funnel. The inbent proximal part of the interstapedial (*it.st.*) fits, by its gently convex condyle, into the gently concave outer face of the stapes (*st.*); apparently there is a joint-cavity here. Three fourths of the trough, which has a thick cartilaginous rim, is filled up by the inner inbent part of the interstapedial.

The trough and the fenestra were forming in the *first* stage (Plate 56. fig. 5, *fs.o.*); the stapes was developed in the *second* (Plate 57. fig. 2, *st.*); but in the *fourth* stage (Plate 58. fig. 3) there was no cartilaginous "columella," the differentiation of which is very late; and this element, although correlated with, is evidently not a part of the stapes.

Certain *deep laminæ* of fibrous tissue which had undergone ossification have been described as part of the largely ossified chondrocranium. Of these the pterygoid and articulare have largely used up the cartilage to which they were applied and related; but one of these plates, contrary to the wont of the Batrachia, has failed to do so, namely, the "superethmoidal" (figs. 1 & 3, *s.eth.*). I class it, however, with the endoskeletal bones in this group. Its counterpart in Bony Fishes may or may not attack the cartilage. Another bone, the quadrato-jugal, is a mere splint in the *Sauropsida*, but is a grafting-bone in the Batrachia. I think it better to keep it amongst the "investing bones," which are ossifications of *shallow laminæ* of fibrous tissue.

The first of these outer bones to appear was the parasphenoid (*pa.s.*), and it is now the most remarkable. This bone (fig. 2) reaches nearly to the foramen magnum behind, and almost to the premaxillaries in front. It is the perfect miniature of a straight sword with a blunt tip.

Protecting the under face of the blade of this bone, near its tip, is a small, transverse, bony shield, the vomer (*v.*); azygous only in this kind of Batrachian as far as I know (see "Frog's Skull," plate ix. fig. 2, *v*); here it has a rounded front and hind margin, and a rounded lobe on each side. In the notch between the front and side there is a strong ligamentous band which attaches it to each premaxillary.

The nasals (figs. 1, 3, *n.*) are small crescentic bars, lying on the hinder face of the large labial pouch (*u.l.*), and attached by their broader inner end to the second small labial ($u.l.^{b}$).

Together, the premaxillaries and maxillaries (*px.*, *mx.*) form an elegant arch, the two former being the keystones; these have a sinuous palatal process (fig. 2) below, and a trifoliate nasal process (fig. 1) above. The maxillaries (*mx.*) are thickish, gently curved bars, rounded above and scooped below; the whole series is dentigerous, and the maxillary teeth run back four fifths of its length. The jugal, non-dentigerous ends of the maxillaries end at an imaginary transverse line drawn through the middle of the skull.

Behind the interlocked junction of the maxillaries and premaxillaries, there is a seed-like ossicle; it lies on the neck of the great labial pouch; this is the "septo-maxillary" (*s.mx.*).

Over the great fontanelle (fig. 1, *fo.*) there now lies a huge slab of bone, which has shelving sides and ends, and a ridged top, like a "ridge-tile;" it reaches from the middle of the superethmoidal bone (*s.eth.*) to near the verge of the foramen magnum: this is the fronto-parietal; it is nearly all due to the frontal "centre." This roof-bone is very much unlike the counterpart in the Frog and Toad (see "Frog's Skull," plate ix. fig. 1, *f.p.*), where each "fronto-parietal" keeps distinct from its fellow, and their edges dip towards each other.

On the hind part of the cheek, also, the bones are not like those of ordinary Batrachia; the squamosal (figs. 7, 8, *sq.*) is not like a hammer, but a knife whose blade is upturned, and whose handle is excavated near its end. Here the "handle" part is absent, as in the *Chelonia.* So also is the quadrato-jugal (figs. 7 & 8, *q.j.*), like that of a Tortoise; it lies directly beneath the squamosal, is grafted on to the lower part of the "otic process," and clamps the outer face of the quadrate in front. The long blade of the squamosal nearly reaches the palatine cartilage (*pt.pa.*) over the elbow of the pterygoid; this process is certainly Batrachian, and is wanting in the Tortoise's squamosal. The two seed-like tympanic ossicles are new to me: the upper (figs. 7 & 8, *ty.*^{1}) is attached to the squamosal handle at right angles, and helps a ligament (*t.l.*) to finish the foramen for the columella. The second tympanic (*ty.*^{2}) is a bent ossicle; it lies, as a clamp, on the upper part of the junction of the quadrato-jugal and quadrate.

The "dentary" (fig. 3, *d.*) is the last of these investing bones; it has already been described.

I forbear to make any further remarks on the strange features of this *Aglossal* type, until the other, namely *Pipa*, has been described; these two, the Cape and the Surinam Toads, differ almost as much from each other, *in details*, as they do from the ordinary Batrachia.

On the Skull of the Surinam Toad (Pipa monstrosa).—*First stage, Embryos from the dorsal pouches 9 lines in entire length**.

This type has broken away from almost all the customs and observances of the Batrachia, being, indeed, a prolepsis of the "Abranchiate" Vertebrata. The lateral and dorsal views of the embryo show how unlike to a *Tadpole* it is (Plate 60. figs. 1 & 2); in its development it does not observe the times of the other Batrachia, but hurries, so to speak, through its stages, like a creature of high degree.

Altogether, this embryo is much more like that of the Salmon ("Salmon's Skull," plate i.) than an ordinary Tadpole. As in the larval *Dactylethra*, there are no horny jaws, and at this stage, as in the Urodela, there are no labials. In my youngest *Dactylethræ*, very much larger and more developed, generally, than this, the limbs were minute bud-like masses of cells; here they are relatively large, and the hind limbs show distinct toes. The intestinal coil was perfect in those free swimmers; here the yelk is scarcely used; it is a mass $\frac{1}{4}$ of an inch in diameter, and the tail of the flat, tape-like embryo almost meets the chin. In the larval *Dactylethra* the gill-operculum is open on both sides, not on the left only, as in common Tadpoles; here, with limbs such as usually are seen when the tail is lessening, the operculum (Plate 60. fig. 1, *op.*) is a small free flap, growing back from the angle of the gaping mouth. This operculum is like that seen in the "first stage" of the Salmon ("Salmon's Skull," plate i. figs. 3 & 9, *op.*). The gills are well developed in *Dactylethra*; but I had no stage in that type to show the external free branchiæ, as in the Frog ("Frog's Skull," plate iii. fig. 10). In *Pipa*, as in *Salmo*, there are no signs of such filaments (this embryo is immature enough to show them if they existed), and there are no branchiæ under the operculum, although the arches (Plate 60. fig. 4) are all present, and the vascular arches are here also. The normal *free branchiæ* exist in the unborn young of *Salamandra maculosa*, and are just aborted at birth; here, neither kinds have been found. As in the first stage of the Salmon, with which these embryos are in *structure* and in *stage* so closely comparable, the skull is largely membranous; it is only floored with cartilage; the brain is quite visible through the delicate gelatinous roof; and the eyeballs lie loosely, as it were, in their sockets, as though they had been planted in them, and were not a part of the primary structure (Plate 60. figs. 1, 2, and "Salmon's Skull," plate i.). The ear-sacs, with the hind brain, take up half the head, so large are they, much larger than in the Salmon's embryo, or in their counterpart in the Toad and Tadpole (Plate 55. fig. 3, *au.*). Moreover, in many respects, Tadpoles of the Common Frog and Toad only half the length of these embryos of *Pipa* are more advanced, and are free active individuals at one third their length. But in *Pipa* the whole metamorphosis is perfect before they awake; for they lie wrapped up like unborn Lizards, not in a proper primary uterus or oviduct, but in a *secondary* dorsal marsupium.

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* For these youngest *Pipæ* I am indebted to Dr. Günther, F.R.S.; for the ripe young from the maternal dorsal pouches to Prof. W. H. Flower, F.R.S.; and for the adult skull, already *partially* worked out by him, and described in the article "Amphibia," p. 756, I am indebted to Professor Huxley, Sec. R.S.

Notwithstanding the slight advance in the parts relating to *organic* life, the *animal* organs are fast advancing; the skull (Plate 60. fig. 3), in this recently differentiated band of blastoderm, is well nigh as far advanced as that of the youngest *Dactylethra* (Plate 56. figs. 4, 5).

These two "chondrocrania" come much nearer to each other than to those of the common kinds, and they mutually illustrate each other; yet, for all that, they are very diverse from each other. Here, as in *Dactylethra*, only the *floor* is, in this stage, solidified into cartilage, and in this type the basal view gives most of the morphology. In both the pituitary floor is chondrified earlier than in the Frog, and in *Pipa* it must have rapidly filled in. In few embryos have I seen such a long cephalic notochord (fig. 3, *nc.*): it is *half* the length of the chondrocranium, in the Tadpole of *Dactylethra* it is one third,—that is, in the latter the trabecular region is twice as long as the parachordal, and in the embryo of *Pipa* they are equal. This is partly a peculiarity of the type; but it shows that these embryos whose chondrocranium can be compared with that of the active Tadpoles of *Dactylethra* are very young, and that they develop with great rapidity. The "first stage" of the Pig's skull shows a similar state of things ("Pig's Skull," plate xxviii. fig. 8). The long parachordal tracts (Plate 60. fig. 3, *iv.*) are much more distinct from the auditory capsules than in the corresponding skull of *Dactylethra*;

these tracts do not reach to the notochordal apex, which is embraced by the apices of the trabeculæ. All trace of the composite nature of the cartilage there, is, however, obliterated, and from the "atlas" to the front wall of the face all is one continuous sheet of cartilage. The large primary, pituitary space (Plate 55. fig. 1) is, indeed, filled in here; but at the middle a faint line of imperfect chondrification can be seen, and thus the distance from this line to the small crescentic "subocular fenestra" (*s.o.f.*) gives the breadth of the trabecular band (*tr.*). This breadth is doubled in the internasal (*i.n.l.*) region, for here the converging trabeculæ have coalesced, back to back.

The trabeculæ, as in *Dactylethra*, do not end in the front wall of the face; their coalesced internasal portion ends there in a transverse, slightly emarginate plate; but externally the two bars are free again, and those distal, or "hypo-trabecular" continuations of the trabeculæ are the "recurrent cornua" (*c.tr.*). These cornua are much more suddenly bent backwards than even in *Dactylethra*; in the higher types, with much more *compressed* faces, these horns lie near each other, and often more or less coalesce ("Pig's Skull," plate xxxvi. fig. 1, *c.tr.*, *rc.c.*). Here the cornua end in a rounded spatula, which lies upon and almost coalesces with the "prenarial lamina" (*p.n.l.*), which is, here, a projection from the pterygopalatine band (*p.pg.*), and becomes the prepalatine spur. *Pipa*, in these things, is in essential agreement with *Dactylethra*; but the head is much more flattened out in the latter than in *Pipa*. The well-marked lateral part of the trabecular floor next to the subocular space (*s.o.f.*) is similar in both types; in both it forms a flap with a convex outer edge. The recurrent trabecular cornua not only lie on the conjugational part of the next arch, but they also close in upon the bars of which they form the distal ends. Thus is formed, outside the "internasal plate," by this looping of each bar, the space by which the outer nostril opens into the fore palate (*i.n.*). In *Dactylethra* (Plates 56 & 57) the outer nasal space is formed in the same manner; but the next bar (*p.n.l.*, *p.pg.*) assists to finish the loop, and the space itself is transverse, whereas in *Pipa* it is almost longitudinal. In the latter the transverse part of the trabecular internasal plate, in front, is of much less extent, and the inner cells of the upper lip are not yet chondrified, so that here we miss not only the tentacles, but also the long, transverse, upper labial, from which they spring.

Coming to the first facial arch, the mandibular, we find all its proximal part in close relation with the great trabecular sheet of cartilage. Moreover, here the morphological stage is one much further advanced than in the youngest larvæ of *Dactylethra*, and more in accordance with the fourth stage (Plate 58. figs. 2 & 3); this is further evidence of rapidity of development; at any rate it shows quick morphological change in these parts, the condition of the embryo, as an individual, being so immature.

The whole pier (the free part of the mandible has been removed, see fig. 4) is a multilobular plate, whose inner lobes are confluent with the trabecular margin (Plate 60. fig. 3, *pd.*, *tr.*). The hinder of these (*pd.*) is a wide flat plate of cartilage which runs in obliquely between the auditory capsule and the posterior end of the trabecula; with this it has completely coalesced, with the other partially, on its outside.

The convex margin of the subocular fenestra (*s.o.f.*) is the concave margin of the mandibular pier, which, in front of this, passes again into the trabecula, and then grows a little forwards into an auriform lobe: the conjugational part is the ethmo-palatine (see figs. 5 & 6, *e.pa.*); the free lobe, in front, is the prepalatine spur (*pr.pa.*),—in the early stage of a Batrachian embryo this is the "prenarial ligament" or "lamina," as the case may be. On this foremost bifid lobe the dilated end of the trabecular "cornu" rests (*c.tr.*). Outside the rudimentary palatine cartilage there is a large semicircular notch, and the lobe bounding this outside is a rounded condyle, the condyle of the quadrate (*q*), on which the *scooped* upper face of the free mandible hinges (fig. 4, *ar.*, *mk.*). On the upper face of the quadrate angle (Plate 61. fig. 1, *or.p.*), the outer muscles of the cheek run to be attached to its outer side, and the temporal muscle runs under and within it; it does not attempt to make a bridge across to the ethmoidal region of the trabecula, for it is scarcely as much developed as in *Dactylethra* (Plate 56. fig. 4, *or.p.*). The sinuous facet for the hyoid arch (fig. 3, *hy.c.*) is close behind the condyle of the quadrate, but it lies further outwards (compare figs. 3 & 4, the latter of which shows the arches that have been removed, *ar.*, *mk.*, and *c.hy.*).

But, unlike other types, the outer part of the quadrate sends a process, outwards and backwards, the lower face of which process is faceted for the *evanescent* hyoid bar; the process and the facet are as evanescent as the bar, which soon wholly disappears. Between the lobe for the hyoid and the last and longest of these lobes there is another semicircular notch, and from thence a long finger of cartilage grows backwards and slightly outwards. This long lobe rests its end beneath the tegmen tympani (*t.ty.*), at its foremost third; it is a little longer than the flat inner process, and its rounded end is free; this is the otic process (*ot.p.*). This spur is quite similar to what may be seen in the adult *Proteus* and the young (half-grown) Axolotl; it is far more developed than its counterpart in the fourth stage of *Dactylethra* (Plate 58. figs. 2, 3, *ot.p.*). The eyeball rests upon the broad central part of the mandibular pier, a little to the outside (Plate 60. fig. 3, and Plate 61. fig. 1, *e.*). Altogether, this fixed part of the mandible is very much advanced for so young an embryo.

The free part of the arch (fig. 4, *ar.*, *mk.*) is an elegant bow, moderately bent, and whose lateral "horns" bend gently backwards to where they are fused. This fusion of the free mandibles is rare in the lower types; it is perfect in some Mammals ("Pig's Skull," plate xxxi. fig. 7*a*, *mk.s.*); at present there are no "inferior labials," and I question their existence separate from the fused ends of MECKEL'S cartilages. The upper surface of the articular region (*ar.*) is cleanly scooped out to roll on the rounded condyle of the quadrate. There is no bony investment to the mandible, as there is none to the chondrocranium generally.

The early visceral cartilages seen in the under face (fig. 4) have much in common: they are all united together by fusion at the mid line; but the last four pairs of bars also catch each other's edges, and unite, both above and below, to some extent. The second postoral arch (*c.hy.*) is large, more than twice as large as the rest; it is longer and less massive than in the Batrachia generally, being intermediate between that of an ordinary Tadpole (or even that of *Dactylethra*) and the hyoid of an adult *Salamandra maculosa*. It is also peculiar in uniting with its fellow, and showing no separate basal piece (compare Plate 56. fig. 6 with Plate 60. fig. 4, *c.hy.*).

The remaining four arches are the "branchials" (*br.* 1–4): these, where they touch above and below, are coalesced; they have no basal piece chondrified, although between them they have not only the rudimentary larynx (*lx.*), but also a large triangular patch of dense granular tissue, which chondrifies afterwards. These bars are flat, thin, somewhat pointed above, and below meet in one common isthmus uniting the right and left bars. These bars are supplied with the usual branchial arteries; but I can discover neither secondary branches to these, nor branchial filaments to which such branches should be distributed.

Notwithstanding the feeble condition of these bars, this is their highest state of development (compare Plate 58. fig. 1 with Plate 60. fig. 4, *br.* 1–5); they, indeed, remain in a fused and altered state; but the hyoid is at its height now, and will have vanished in the ripe young (Plate 60. fig. 7).

There is no such superfluity of cartilage growing from the auditory capsules as in *Dactylethra*; but the tegmen is a very distinct eave to the huge ovoidal capsules; they are fully chondrified, even above, and so quite come up in this respect to the first stage of *Dactylethra* (Plate 56. fig. 4). Beneath, the fenestra ovalis and its enclosing fossa is more advanced than in that larva. It nearly corresponds with that of the Common Toad's Tadpole when it is two thirds of an inch long, a little shorter than these embryos of *Pipa* (Plate 55. fig. 5), but which has been for two or three weeks an active self-determined larva.

In this stage the future fenestra ovalis (fig. 3, *fs.o.*) is a somewhat triangular depression, with the longest angle, like a lacerated wound, running backwards and a little inwards; in this, its faintest part, the perforation will take place. The obtuse, middle angle of this fossa looks inwards, and the foremost, which is rounded, forwards and outwards. Above the crescentic open space between the front of the capsule and the mandibular pier the 2nd and 3rd branches of the trigeminal nerves pass towards their destination; below that space the *thyroid gland* (?) (*tr.g.*) lies; behind the capsule the 9th and 10th nerves are seen emerging.

No further light upon the morphology of this peculiar chondrocranium was obtained by upper views, and only a partial figure of that aspect is here given (Plate 61. fig. 1), to show the size and relations of the "orbitar process." At present the side walls of the skull are not chondrified, and the conjoined trabeculæ form merely a flat internasal plate*.

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* Notwithstanding the anxious care required to work out such chondrocrania as this and that of the younger *Dactylethra*, I consider that their elucidation has amply repaid me; they light up each other, satisfying the self-suspecting observer, when he sees the most strange modifications reappear a little altered. Conforming in all essentials to typical, larval, skulls of Batrachia, their most striking aberrations will be found to have meanings that relate to types beyond their own group, meanings also that will not all meet the eye until more is seen and known.

On the Skull of Pipa monstrosa.—*Second Stage. Ripe young,* $6\frac{1}{2}$ *to* $7\frac{1}{2}$ *lines in length.*

In this stage all the figures except one (Plate 60. fig. 7, *the mandible and branchials*) are from young that were showing their faces at the mouths of the dorsal pouches; these were $7\frac{1}{2}$ lines, or nearly two thirds of an inch, in length. The others were still rolled up and were slightly above half an inch, in length. Yet these *unawakened* larvæ were perfectly metamorphosed, and I could see no difference whatever, even in the degree of their ossification, which was intense, and far beyond what I expected to find in such small young of so large a species. Now in the earliest stage I have (Plate 60. figs. 1, 2) the entire length was 9 lines, nearly *half* the length being due to the tail; therefore it is seen that when metamorphosis is perfect the body is only one fourth of an inch longer than it was at the time that the yelk-mass was but little lessened in substance (not at all in *size*), and that the series of somatomes perfect themselves into the body, vertebræ, muscles, &c., by filling in, as it were, the original map, and scarcely modifying the size of the territories. Also it may be remarked that the head of the early embryo (Plate 60. figs. 1, 2) is *two lines*, or one sixth of an inch, in length, the condition of whose skull has just been described (Plate 60. fig. 3); whilst the head of the *unrolled* young is three lines long. Thus it is seen that the lengths are (without the tail) as follows:—Early embryo: head $\frac{1}{6}$ inch, body $\frac{1}{4}$ inch; total $\frac{5}{12}$ inch. Ripe young: head $\frac{1}{4}$ inch, body $\frac{1}{3}$ inch; total $\frac{7}{12}$ inch (taking the average of the two sizes of the young *Pipæ*).

The figures of the chondrocranium (Plate 60. figs. 3, 5, 6), the degree to which they have been magnified being considered, show how much the metamorphic action has modified the condition, and how little the size; a like case to that with which all are familiar, namely, during the "vernation" of trees (*e. g.* of *Æsculus*), when the new internode gains its length in three or four weeks, and takes the rest of the season to stiffen itself by deposit*.

The unexpected *finish* of these ripe, or nearly ripe, young *Pipæ* makes it necessary to modify, a little, my mode of illustration. The figures of the chondrocranium at this stage (Plate 60. figs. 5, 6) are made by drawing the still existent cartilage, and leaving out in those figures the *ectosteal* deposits (see, in contrast, Plate 61. figs. 2, 3).

And here is another anomaly, namely, that whilst the cartilage has been *used up* in the auditory capsules, leaving large spaces, above and below, only invested by bone, the same thing, contrary to wont and experience, has taken place where the great parasphenoid lies (Plate 60. fig. 6, and Plate 61. fig. 3; compare with these the adult Toad's skull, Plate 54. fig. 4). Here the development of an underlying "parostosis" has been coupled with the absorption of the *newer cartilage* of the primary pituitary space (see Plate 55. fig. 1, *pt.s.*), which lies upon that splint-bone. Here, again, in a Batrachian we see the want of any proper boundary line between a *parostosis* and an *ectostosis*, the difference between which is so clear in "Teleostean" Fishes, and the "Sauropsida," generally.

Such a chondrocranium as we see here (Plate 60. figs. 5, 6) is a fair and clear diagram of the Batrachian type of skull, if we make allowance for the absorbed floor-plate. Yet at once we see a modification, for the occipital condyles (*oc.c.*) are more *outside* than behind. The absorption of the cartilage in front of the notochord takes place wittingly, as it were; it has marked out, again, the parachordal region (*iv.*) by absorption of the apices of the trabecula (see Plate 55. fig. 1, *tr.*) along with the newer cells of the pituitary floor. The notochord (*nc.*) is but little diminished; even now it lies mainly *over* the parachordal floor behind, and is free over the parasphenoid in front. On each side a fissure marks the almost absorbed auditory cartilage from the parachordal plate, and in front of that chink the auditory, parachordal, trabecular, and mandibular cartilages are all confluent, and form a gnawed tract on either side. Just where the optic nerves (2) pass out, there the trabecula is reduced to its primary size. But from thence each bar rapidly widens, running inwards to meet its fellow, and to form the ethmoidal floor: on this floor lie the olfactory lobes and the anterior *fourth* of the hemispheres (C 1). This zone is narrow above (fig. 5), and is there to be seen as the elegant arcuate front and junction of the steep side walls, which thin out extremely before they pass into the crest which runs from the auditory capsule (fig. 5). The ethmoidal belt, in front, grows into a median crest or keel and a pair of side wings: the keel is the septum nasi with its "cornua" (*s.n.*, *c.tr.*), the side wings belong to both the trabeculæ and the palatines (*e.pa.*).

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* There is a familiar instance nearer home, namely, in the *almost completed length* of the foal's "metatarsus" and "metacarpus" at the time of birth.

This keel, and these "horns," are explained by the early stage (fig. 3), and they serve as a key to open the mysteries of the adult skull at this part (Plate 62). In front of the palatine conjugations the trabecular internasal plate has been reduced to less than one fourth of its former width (figs. 3, 5, 6). This narrowing produces a large crescentic notch on each side, which is, externally, the hind margin of the inner nostril. The subnasal lamina, or primary trabecular commissure, dilates twice, beyond the middle and in front, but is nowhere wider than the same winged part in a Passerine bird. In front the septum is broad, for the internasal plate there grows up into a wall, the rudiment of the alinasal laminæ; from this wall, above, the cornua trabeculæ pass backwards: the stem and the arms of this structure look like a miniature of the "governor" of a steam-engine.

When this fore part is cut through at the front of the septum nasi and in the roots of the "cornua," then it is seen that the septum is a thick and high wall, and that the rudimentary alæ nasi (fig. 8, *s.n.*, *al.n.*) are also thick, and have rounded inferior edges. Above, from the very narrow aliethmoidal bands (*al.e.*) to the front, the aliseptal plates (*al.s.*) are scarcely at all produced right and left (Plate 61. fig. 5).

The backgrowing "horns" of the trabeculæ (Plate 60. figs. 5, 6, and Plate 61. figs. 4, 5, *c.tr.*) form a small angle with the septum, and have a knobbed free end; they grow from the upper part of the internasal plates, and therefore lie nearly as high as the roof of the septum. The foliaceous prepalatine (*pr.pa.*) runs forwards outside, and parallel with the trabecular horn, but free of it, instead of being nearly flush with it and more or less coalesced, as in the embryo (fig. 3, *p.n.l.*).

The nasal capsules are thus seen to be but little indebted to trabecular outgrowths for their protection; these latter are somewhat supplemented by the upper labials (*u.l.*) to be described soon.

The changes that have taken place in the mandibular arch are easily traceable; the pedicle (figs. 5, 6, *pd.*) is long, the broad central part of the pier is now lost in the outer lobes, which now lie outside the foremost part of the auditory capsule. The two inner arms of this plate (compare figs. 3 & 6) are much altered by elongation and attenuation; and whereas the hinder (*pd.*) ran backwards to join the trabeculæ, it now runs forwards; also the front bar, which ran forwards, now runs backwards as well as inwards (figs. 5 & 6, *e.pa.*).

The former of these is now a narrow band which is dilated into a broad plate, where it joins the trabecula (*pd.*, *tr.*); the latter has grown now into three distinct regions, namely, the ethmo-palatine (*e.pa.*), the prepalatine (*pr.pa.*), and the common postpalatine and pterygoid bar (*pt.pa.*, *pg.*). This bar is now sigmoid in shape, and of great length; it sets on to the fore face of the quadrate close within the condyle, and is elbowed out just before it joins that part: two longer elbows, but less bent outwards, are seen, the first where the palatine runs into the pterygoid region, and the next at the root of the leafy prepalatine. This latter part (once the "prenarial lamina," *p.n.l.*) is a further development of the secondary antero-internal lobe; the secondary growth on the antero-external lobe, the process for the condyle for the hyoid (*hy.c.*), is now obliterated; this is a correlate of the absorption of the cerato-hyal (fig. 7).

The two external lobes are now seen to have become the outturned, scooped quadrate trochlea (*q.*); and the inturned otic process (*ot.p.*) a triangular wedge with a rounded apex, over which the columella (*it.st.*, *m.st.*) passes. Here the articular portion of the quadrate cartilage is a deep trochlear groove, the cartilage being most curved away below; it was a rounded condyle (fig. 3, *q.*). On the other hand, the articular surface of the free mandible (fig. 7, *ar.*) is a sinuously rounded head, and it was (fig. 3, *ar.*) a scooped hollow on the upper face of the end of the cartilage. The dilated end of the cartilage is covered with a bony sheath (fig. 7, *ar.*) which attenuates gradually forwards, clinging to the inner face of the rod, and ending near the symphysis in a point; this is the ectosteal "articulare," which ossifies the proximal part of the mandible. On the outer side is a bone (*d.*), the dentary; its broad part is in front of the symphysis, where it is tied to its fellow, and it ends where the upper third of the bar begins. Much of MECKEL'S rod is unossified within these two bones; there is no "os Meckelii" or mento-Meckelian element.

The cerato-hyal has disappeared; I have indicated its empty place by a dotted line (fig. 7). In the upper and anterior region of the second postoral arch there is a considerable osseo-cartilaginous bar (Plate 60. figs. 5, 6, and Plate 61. figs. 2, 3, 6); this is the columella: it is attached behind to the stapes (*st.*), now fully developed. All these things are new since the early stage in which all that was formed was a fossa containing gelatinous stroma. I strongly suspect that the development of these embryos is very rapid, for the lesser of the young in this stage are but little larger than the recently changed

Common Frogs and Toads; and the larger young are less than the Toad when its columella is first a cartilaginous rod (Plate 55. figs. 6–8).

But in these young *Pipæ*, with the body so little longer than that of the early embryo (figs. 1, 2), the columella is as perfect as it is in our common kind at the end of the first autumn. Supposing, as I do, that the stapes was solidified first, yet there was little time lost in either; thus this type begins to break down that want of synchronism in the development of the upper and lower rods developed as parts of the "2nd postoral."

Another matter of importance in this type is this, namely, that the *stapedial* fossa is nearly obliterated in front, and that the almost contemporaneous stapes and columella are related to each other in a manner which is, to say the least, very Mammalian. Let the short crus of the Mammalian *incus* be merely the upper "ear" of a heart-shaped cartilaginous "body"; let the "os orbiculare" ossify two fifths of a stout and somewhat outbent "long crus," the rest having its own centre, and stopping at the "body"; lastly the fenestrate part of the stapes is to be arrested,—and then this supposed modification of the Mammalian *ossicula* would exactly correspond to what really exists in *Pipa*.

But in this type the stapes is a neatly oval plug (Plate 61. fig. 6, *st.*), the flat face of which is outside, and the convex face placed inward, fitting into a funnel-shaped fenestra ovalis (*fs.o.*), the open mouth of which is the developed form of the long hollow (as though a piece had been torn away from the outer coat) which is seen in the first stage (Plate 60. fig. 3, *fs.o.*). Already the fenestra ovalis has been brought to the supero-external edge of the capsule, an elegant wedge of *opisthotic* cartilage finishing the outer margin above (Plate 61. fig. 6). In front of the fenestra the tegmen tympani (never large, see fig. 3) is receiving its squamosal investment (*sq.*), and that in a truly remarkable manner. Behind, it is a film tiling the auditory eave; it then creeps upwards to the cartilaginous selvage of the common bony plate, in which is seen the sweep of the horizontal canal (*hs.c.*). The descending growth of the squamosal in the outer face of the quadrate (*q.*) is hidden by the columella; but there is here an elegant anterior process (the long front part of the *hammer-head* in the common form of the Batrachian squamosal, Plate 54. fig. 7, *sq*,); this is growing into a cochleate process, and in this "spoon" the extrastapedial (*es.t.*) and "annulus" (*a.t.*) lies. The *side* of the auditory capsule being thus tilted up, the columella lies *on* the stapes, mandibular pier, and squamosal, and *outside* the diminished "tegmen"; it is well seen from above, although it is placed obliquely.

The primary cartilaginous rod is pinched in at two places, marking off the three regions, namely, the interstapedial (*it.st.*), the mediostapedial (*m.st.*), and the extra-stapedial (*e.st.*); in this, as in the other *Aglossal* Toad, there is no ascending supra-stapedial ("short crus"). The well-developed bony shaft covering the interstapedial region (*long* in the Toads, and not cut off as a distinct separate cartilage as in the Frogs) is two fifths the length of the mediostapedial (*m.st.*); its fibres radiate over the unossified bulbous end of the bar which articulates with the stapes: in the adult (Plate 62. fig. 9) this is still better seen. In front of the longer mediostapedial shaft-bone the cartilage escaping from the sheath is at first thick, and it bends downwards and inwards before it spreads into the extrastapedial (*e.st.*), which is like a water-lily leaf, as in *Dactylethra*.

In the interim between this and my first stage I have missed the formation of the U-shaped "annulus" (*a.t.*) on which the lips of the extrastapedial rest, but I have traced its formation in several kinds.

The rest of the auditory capsule may be described here.

The extreme degree of ossification of the whole "occipito-otic" region satisfies me that here, as in *Dactylethra* and *Pseudis*, it would at any time have been impossible to find any gap between the exoccipital and the prootic. These parts are now like a hard double fruit, with as hard a connective between them; this intermediate part is all strong, save at the mid line below (Plate 61. fig. 3, *b.o.*, *e.o.*). On the lower surface of the hard ear-ball there is also a break in the bony covering, like a line of dehiscence running in from the middle of the outer edge. This chink in the hard floor is, however, due to the manner in which the bony growth has radiated; it marks out the prootic region in front from the opisthotic behind; but it does not, even in the adult (Plate 62. fig. 9), run round behind the fenestra ovalis to form the well-known *opisthotic hook*, as in the Common Toad (Plate 54. fig. 7, *op.*). This common bony floor grows, shell-like, to the front edge of the capsule, but leaves an external lip of cartilage, and fails to floor it in towards the inner edge also. Where it curves and narrows inwards, running round and between the ninth and tenth nerves (9, 10), it floors three fourths of its own side towards the basioccipital synchondrosis, with the overlying notochord (*n.c.*). The bone runs to the lower edge of the foramen magnum (*f.m.*), leaving the middle and the condyle (*oc.c.*) soft. That condyle shows most above (fig. 2), and its face looks upwards and outwards; its shape is oval, and it is unusually flat.

Embracing these facets, the bone then wholly enarches the foramen magnum and the superoccipital region (*s.o.*); but beneath the bone the cartilage is perfect (Plate 60. fig. 5, *s.o.*). The whole oval top, which is larger than the floor, is roofed with continuous bone, which has set up absorption in the cartilage beneath (Plate 60. fig. 5), but not to the same extent as in the lower face. Through the strong but thin ectosteal plate and cartilage the semicircular canals (they are represented by dotted lines) can be seen in a well-prepared skull, examined as a transparent object *.

The cartilage reappears in the alisphenoidal region in front, and in the tegmen outside (figs. 2 & 6). The chondrocranium has other ectosteal plates that properly belong to the endoskeleton. One of these can be detected binding together the frontals (fig. 2, *f.*), which has, however, but little independence as a bone; this is the superethmoidal plate (figs. 2 & 4, *s.eth.*), a large and permanently distinct bone in *Dactylethra* (Plate 59. fig. 1), but here already a mere spike and under-thickening to the middle of the fore edge of the common frontal plate (*f.*). The pterygoid bone (Plate 61. fig. 3, *pg.*)

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* After careful dissection, these skulls are treated with an ammoniacal solution of carmine, and then placed in glycerine.

invests the lower face of the cartilage both in the pterygoid and metapterygoid regions. This triacanthous plate binds on to the inner face of the quadrate (*q.*), and the under face of the pedicle (*pd.*), and of the lateral pterygoid bar of cartilage.

Then, except where it is invested by the maxillary (*mx.*), which runs to the inner side, almost meeting the pterygoid, the three regions of the palatine cartilage seem free from ectostosis. With great care, however, there may be found a style attached to the hinder face of the ethmo-palatine below; it runs outwards and forwards, and sets a pedate base against the antero-external angle of the parasphenoid (*pa.s.*): this is the ectosteal palatine (figs. 3 & 7, *pa.*); it exists in the Batrachia generally, but not in *Dactylethra* (Plate 59. fig. 2)*.

The above, with the pair of bones in each columella, and the "articulare" in each mandible, are all the *deep-layer* ossifications I can find in this stage; they are bones that can be easily identified with their homologues in Osseous Fishes, Sauropsida, and Mammalia.

The "investing bones" are of great interest in this stage and in this type; the largest and earliest of these is the parasphenoid (fig. 3, *pa.s.*). This huge bony shield is not like what we see in the Batrachia generally, but resembles that of an adult "Perennibranch," or a young "Caducibranch" Urodele. Its hinder half is the narrower; it gradually loses breadth behind, and then its rounded hinder margin sends backwards a sharp spike. In front it is also spiked, and then, for a short distance, is only one third its full breadth, but, by a sudden step on each side, attains it rapidly. Its narrowing takes place suddenly again, where the broad foot of the "pedicle" joins the trabecula. Beneath its front spike *there is no vomer*. A somewhat larger space is covered by the roof-bones above (fig. 2). This large bony part is very similar to that below; it is, however, convex along two lines and somewhat depressed along the middle, whereas the parasphenoid is convex generally. The upper tract is spiked in front, but from a borrowed source, the superethmoidal. It is *winged* in front; but the upper belong to it, whilst below they are borrowed. Behind, the roof is crenate and not spiked. This part is also formed, not from one, but from four centres, namely, the frontals, which are twice the length and breadth of the others, the parietals (*f.p.*). The anterior frontal wing (prefrontal process) binds the ethmo-palatine above, just as the palatine style binds it below. As the bony roof is larger than the floor, so the space to be covered (Plate 60. fig. 5) is also larger. As in *Dactylethra*, there are no *secondary fontanelles* to be covered by the parietals, it is all one pyriform space.

The narrow walls and spurs between and around the nasal mucous membrane, exposing it largely in the chondrocranium (Plate 60. figs. 5 & 6), are largely supplemented by investing bones. The main pair are the nasals (Plate 61. figs. 2 & 4, *n.*); they are large bones, nearly semicircular, but their obliquely placed transverse margin is deeply notched for the external nostril (*e.n.*). Their round hinder edge is overlapped by the frontals, and their outer edge, in turn, overlaps the marginal bones externally and the ethmo-palatine bar (a little) behind. The large anterior sinuous narial notch is of great interest, as it makes the nasal bone of *Pipa* the prototype of that of a "Carinate" bird. The hinder of the marginal bones is a "preorbital" (Plate 61. figs. 2, 3, 4, *p.o.*). It is not common in the Batrachia, but exists in *Rana pipiens,* and is well seen in *Clarias capensis*, a "Siluroid" fish; here it is a thin bony scale, broadest behind, and having its thin inner edge deficient at places, forming teeth and hooks; it helps to set bounds to the outer nostril. But the outside of the nostril (*e.n.*) is finished by a much smaller bone, the septo-maxillary (*s.mx.*); it is set on the narrow end of the last, and is a sigmoid rod, bending first outwards and then inwards; it ends in the front wall of the face in a blunt point; this is the bony element of the curious nostril-valve. Below, the chondrocranial framework, in front (Plate 60. fig. 6), is strengthened by flat bony splints, the premaxillaries and maxillaries (Plate 61. fig. 3, *px.*, *mx.*); these are extremely embryonic and simple, for they only lie on the under face of the chondrocranium. Their free surface is gently rounded; altogether they are thin and fibrous. The premaxillaries do not meet, yet, beneath the septum nasi, the form of each is an arcuate lobe, rounded within and sharp externally and behind; the outer edge has a round notch.

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* Professor HUXLEY missed this bone in the adult (art. "Amphibia," p. 756). The unlooked-for "wings" to this part in the huge parasphenoid of the adult (Plate 62. fig. 2, *pa.*, *pa.s.*) struck me as abnormal, and led me to make inquisition in the young.

The convex edge of the premaxillary is overlapped by the projecting end of the maxillary. This latter bone is falcate, with distant serrations on its sharp inner edge, and it ends behind as a sharp point, a little in front of a similar point, the fore end of the pterygoid. The pterygo-palatine cartilage bows out beyond these styles. Below (figs. 3 & 7, *pa.*), the palatine style looks like a prop standing out between the parasphenoid and the maxillary.

The squamosals and the dentaries are the other investing bones. These have already been described; there is no quadrato-jugal.

The peculiar valves that protect the external nostrils are strengthened by cartilages within; these are the "upper labials," now at their highest development. They are best seen from above (Plate 61. figs. 4 & 5; Plate 60. fig. 8, *a section*). The most massive of these ($u.l^a.$) lies in the floor of the outer nostril; it is pedate and flattish in front and bulbous behind; the pedate expansion is largest externally. To the hinder bulbous part of this a second ($u.l^b.$) is articulated; it is larger and thinner than the first. Where it articulates with the bulb by a concave margin, there it is squared on its opposite edge. From thence it runs outwards as a narrow, somewhat decurved band, which ends on the upper lip in a point, from which point a sharp hook runs inwards towards the first cartilage. That is its outer end; its inner end runs forward from the squared part, and dilates into a bilobate process that lies against the fore front of the septum nasi. Also on the subnasal laminæ (*s.n.l.*) of the septum, where the trabeculæ retain somewhat of their primordial flatness, there is a small, seed-shaped, third labial ($u.l^c.$). Others than these I have not been able to find; and these are fullest at the ripeness of the embryo, and then waste away by the time the *Pipa* is adult.

All that remains of the hyoid arch (Plate 60. fig. 7) now is the fore end of the basi-hyobranchial bar (see in *Dactylethra*, Plate 58. figs. 4 & 5, *b.hy.*, *b.br.*). This part did not exist in the first stage (Plate 60. fig. 4); but the median bar has appeared with the disappearance of the " cornua," and already the metamorphosed branchials are the very true counterparts of what we see in the adult *Dactylethra* (Plate 58. fig. 5), save that the hyoid bands are gone.

Here the second basibranchial (*b.br.* 2) has now become cartilage (Plate 60. fig. 7, *b.br.* 2), and is, relatively, much larger than in *Dactylethra* (Plate 58. fig. 5, *b.br.* 2). In that species, as in *Pipa*, the first basibranchial is fenestrate, and the first and second branchials (*br.* 1, 2) are molten together and spread out into a large flat plate, pyriform here, oblong in *Dactylethra*. Here the third and fourth (*br.* 3, 4) branchials (their lower or hypobranchial ends) have formed the thyro-hyals, but they are not yet ossified as in the old *Dactylethra*. In *Rana temporaria* (" Frog's Skull," plate x. figs. 1 & 2, *th.*) there is no second basibranchial to underlie the larynx (*lx.*); and, seeing the relation of the second basibranchial of the Newt to its larynx, Professor HUXLEY has been led to doubt the correctness of my description (*op. cit.* p. 185) of these parts. *Pipa* and *Dactylethra* answer for me, for they possess both the median thyro-hyal of the Urodele and the paired thyro-hyals of the Anuran.

The remainder of this demonstration is by far the easier part, for the skull in the little ripe embryos had undergone the most striking and important changes. Its metamorphosis was fairly perfect, relative change of size or degree of hardening being nearly all that remained over to the growing *Pipa*.

Skull of Pipa monstrosa.—*Third Stage; the adult Toad.*

There can scarcely be a more remarkable skull than this; the sense of hearing would appear to be of more consequence to this Toad than that of sight, for the eyes are but little grown (Plate 62. fig. 1, *e*), whilst the organs of hearing are thrown out on long arms much as the eyeballs are thrown out in the Hammer-headed Shark. Therefore many things in the skull are contrary to what we find even in the nearest of kin, namely, the other tongueless kind (*Dactylethra*, Plate 59). The general appearance of the skull suggests the idea of a log-house hastily thrown together, and not a fitly framed structure compacted together with the utmost architectural care and skill. A little of the old cementing cartilage there is, and strong bands and sheets of fibrous tissue in places; but in the main it is made up of slabs, and planks, and bars, placed lengthwise, slanting, and across. These, moreover, look as though they were fresh from the tools of the hasty framer.

Behind (Plate 62. fig. 1–4, *oc.c.*) the occipital condyles have their faces turned the contrary way; they look outwards, and are unusually flat. The dense, stout occipital ring is all bony, save below (fig. 2, *b.o.*); for, true to its Batrachian character, it has a soft basioccipital. The great, outstanding occipito-otic "arms" are one single mass of bone, although on the under face there is a second transverse slab in front of the other and beneath it; this is, however, merely a part of the pterygoid (*pg.*). The exoccipital (*e.o.*), jagged and somewhat bowed, touches the quadrate (*q.*) outside; the prootic region of the bone (*pro.*) stretches to the far-off tympanic apparatus. Wedged in between the inner edges of the exoccipitals, we see an elegant, convex tongue of the parasphenoid (*pa.s.*, its old spike, Plate 61. fig. 3). From thence, by step-like notches and projections, this under slab gains its full breadth under the 5th nerves, and retains it until it gains the palatine "wings." Then it runs, with a rounded margin, rapidly inwards, and ends in the front spike, which runs a little under the septum nasi; this spike is split at its end. Under this part in *Dactylethra* there is a vomer (Plate 59. fig. 2, *v*), but, with Professor HUXLEY, I have failed to find one in *Pipa*.

At this part there are remaining tracts of cartilage, and the ethmoidal belt runs forwards, much narrowed at the septum nasi (*s.n.*), which is thick and rounded below and above; but not alate, except in front. The extreme flattening of the face has caused the septum nasi to be a very low wall, especially in front; in this type the depressed form attains its greatest degree in age, in *Dactylethra* in the embryo.

The small alæ of the septum (Plate 61. fig. 5, *s.n.l.*) are gone, but now there can be seen an azygous process projecting into the front wall, namely, the prenasal (*p.n.*); it is a rounded spike. The depressed septum becomes altogether almost rounded in front, and the alinasal folds (*al.n.*), as seen from beneath, might be supposed to grow from the lower margin of the septum; but they are its roof, but are a very short distance from the floor (compare Plate 60. fig. 6, *al.n.*, with Plate 62. figs. 7, 8, *al.n.*). Now, instead of showing a convex margin, emarginated slightly in the middle, the front is trifid, the middle projection being the spiked prenasal, and the lateral parts thick, cupped lobes, whose concave front face is beset with strong subcutaneous fibres. From this part they throw out, and run gently into the top of the septum within, whilst without they run backwards and outwards, as long, terete, nearly straight "cornua trabeculæ," which end beyond the inside of the prepalatine lobe (figs. 7, 8, *c.tr.*, *pr.pa.*).

The manner in which these trabecular bars have retained their primary recurrent form, and yet have merely become attenuated, is noteworthy (Plate 60. figs. 3, 5, 6, and Plate 62. figs. 7, 8, *c.tr.*). They now form nearly a right angle with each other, and one of less than 45° with the septum.

Here there is no "girdle-bone," the chondrocranium dies out a little behind the ethmoidal region, and the roof and floor meet at the sides (fig. 4). But the unossified cartilage binding the ethmoid with the palatine is guarded by a strong wing of bone, the palatine (*pa.*), which grows out from the angle of the parasphenoid. A vessel passes through the bone where this is given off, and there is an appearance of its former distinctness; this wing, we saw, was developed separately. The ethmo- and prepalatine (*eth.*, *pr.pa.*) regions are present, but the postpalatine bar has been absorbed: if the ethmo-palatine had been segmented off from the ethmoid, as in the Common Toad, then we should have had the free antorbital cartilage of *Menobranchus* and *Proteus* (Plate 54 figs. 3, 4, *e.pa.*; and HUXLEY, "On *Menobranchus*," *op. cit.* plates xxix. & xxx. *A.o.*).

Here it curves forwards because of the original Batrachian form of this arch; there it has no prepalatine spur, and naturally grows backwards, as seeking its next segment the pterygoid. The long tape-like pedicle, and the stout, subconical otic process (Plate 60. figs. 5, 6, *pd.*, *ot.p.*) cannot be traced as distinct processes now; the former is lost, as a process, along the front of the outstretched otic masses; and the latter (*ot.p.*) may be seen as cartilage between the squamosal and the fenestra (figs. 1, 3, 4, 9, *sq.*, *pro.*). With this out-thrusting of the auditory mass the quadrate (*q.*) is carried from the head a great distance, and is, in its hinder margin, opposite the occipital condyles. Its own condyle (figs. 2, 3, 4, 9) is sinuous (cylindroidal), and much of its substance is ossified as a true quadrate bone, enclothed with the squamosal (*sq.*). The facet has a pyriform outline, with the narrow end looking forward and outward; its broad end is below and in front of the posterior margin of the quadrate bone. In front of and below the otic process, the pterygoid (*pg.*) passes forwards nearly at a right angle with the transverse otic masses. This front part of the pterygoid is a large, leafy bar, with oblique fibrous markings; it is narrower and thicker behind, broader and thinner forwards; the outer edge (figs. 2 & 4) is grooved and contains some unchanged cartilage, its inner edge is soft. This falcate part is grooved below for the jugal end of the maxillary (*m.x.*), which it largely overlaps; their overlapping ends are pointed. This fore part is the *shaft* of the hammer-shaped pterygoid; it joins the *head* in a curved manner, running inwards, and the inner part of the head is the longer. Where the inner part clasps the coalesced and undistinguishable pedicle, there is, proximally, an elevation of the bone; it then runs in and stops short suddenly, leaving exposed the roughly ossified pedicle and contiguous part of the auditory capsule. Further back it is longer and more splintery, and reaches one of the steps of the parasphenoid. Behind that spike there is another tract of rough inner bone, and then the long exoccipital; the two bones, externally, fit by a squamous suture. The short end of the "head" runs outwards and backwards, strongly clamping the inner face of the quadrate.

The free mandible (figs. 5, 6) is a strongly bent, rib-like structure; the condyle is also cylindroidal, and seen from above (fig. 5) it has a squarish outline, and is traversed by a concavity; it is obliquely set on the top of the inbent, solid "articulare" (*ar.*), which bends outwards beneath the condyle. The articulare runs to within a short distance of the chin, and is covered by the dentary (*d.*), which is two thirds its length; the transverse front ends of the dentaries form a fibrous symphysis, without an "os Meckelii;" the cartilage is almost entirely changed.

The auditory masses, as seen from above and behind (figs. 1 & 3), are, with their intermediate occipital arch, a most rugged and strong structure.

Already, in the ripe young (Plate 61. fig. 2), these parts were like small stony fruits, the occipital arch being thoroughly ossified by ankylosis of the exoccipitals above; but now it asks some care, if the parts are to be interpreted. The foramen magnum (fig. 3, *f.m.*), like the entrance of some stony cave, is surmounted by rough, projecting blocks of bone. The lower pair of these jutting snags overarch the 9th and 10th nerves (9, 10) in their passage. Above, these angular and jagged masses show the epiotic eminence (*ep.*); formerly (Plate 61. fig. 2) a gentle eminence covered the ampulla and arch of the posterior semicircular canal. Looking above (fig. 1) we see that the arches are now covered by three bony crests, and the interspaces are dug into deep fossæ; the whole bone being excavated, as in certain Osseous Fishes. The ridge covering the horizontal canal runs into the epiotic eminence behind; but in front it runs obliquely outwards as far as to the "tegmen." This crest overhangs the channel in which the "portio dura" (figs. 1, 3, 7), which has escaped from the "trigeminal" (leaves it at the foramen ovale), runs, once more free, along the grooved surface of the bone, to pass *over* the columella.

The vestibular portion of the membranous labyrinth runs outwards, and reaches the stapes in the postero-superior angle of the extended auditory mass.

The primary absorption of the cartilage for the fenestra ovalis (Plate 60. fig. 3, *fs.o.*) was below, and almost central; now the oval, funnel-like fenestra is in the centre of a thick ring of cartilage; it looks equally downwards and forwards, and its larger end, the *prefenestral fossa*, is below and in front. The cartilage above the fenestra belongs to the prootic region, that below it to the opisthotic; there is no *fenestra rotunda* as there is no *cochlea*. Fitting into this auditory funnel is the oval stapes; its inner part is a subconical wedge, its outer part flat; it is relatively small, but its outer face much exceeds that which closes the fenestra. The next part of this truly elegant apparatus is like a *flute-key*; it takes the same direction as the long axis of the stapes, namely downwards and forwards. Here let the reader compare the figure (9) with that of the auditory chain of the Pig ("Pig's Skull," plate xxxvi. fig. 3, *inverting* that plate). Here there is no interhyal (*i.hy.*), and the malleus exists in another form, namely, in the mandible; the stapes, also, has in the Batrachian no fenestrate crest. But the elegant, elbowed rod of bone, sticking, limpet-like, to the face of the stapes, and composed of two osseous centres, these correspond in both. The upper bone is the os orbiculare (*o.ob.*) or interstapedial (*it.st.*); the outer the long crus of the incus (*l.c.i.*) or the mediostapedial (*m.st.*): one difference there is, and not greater than is seen between *Bufo* (Plate 54. figs. 7, 8) and *Pipa*, and that is that the discoid part in the Pig is one centre, and the long crus another; here, in *Pipa*, the discoid part is one with the bar up to the "elbow," and then commences the other bone (*m.st.*). The body of the incus (*i.*) is represented in *Pipa* by a cartilaginous part, not anvil-shaped, but like the leaf of *Nymphæa*; and the short crus (*s.c.i.*) is here represented by a strong fibrous ligament. Another shorter ligament is seen on the underside of the columella; these attach the membrana tympani, "annulus," and extrastapedial to the front margin of the stout ring of cartilage that encircles the fenestra. If all this structure has an *artificial*, and as it were manufactured appearance, equally so has the part in which it is set. As in the common kinds, the squamosal (*sq.*) has a descending body and a double head; the posterior part of the head overlaps the tegmen and otic process, and on the anterior part of the head the drum-membrane and its ring are attached (see in *Bufo*, Plate 54. fig. 7). Here (Plate 62. fig. 9) the squamosal (*sq.*) is most carefully moulded over the front and outer face of the reverted oblong quadrate mass. It leaves the junction of the tegmen and otic process uncovered, has a scooped margin, where it binds against and then retreats from the stapedial encircling ring; it then, by steps, reaches the hinder face of the quadrate, leaving its margin uncovered, but it well enwraps it further forwards, down to the condyle, and round its front edge, ensheathing it by a beak-like folded plate. This is not all, for the middle of its outer face is hollowed into a valley which is bridged over by the columella; and this valley ends in front in an outstanding basin, suboval in shape, but apiculate, and with a fixed base. This *cochleate* process of the squamosal has its edges lined with the almost perfectly circular annulus, whose open part is traversed by the mediostapedial. The apex of the scooped squamosal process projects in front of the annulus; its cavity contains *air*, which it derives from the Eustachian tube, this part being built in the first postoral cleft, and utilizing, as it were, that old chink for these new auditory purposes. Behind the ethmoid, and in front of the auditory masses, the chondrocranium soon dies out; the parasphenoid has a bevelled upper edge, and the fronto-parietal slab has a raised and thick superorbital ridge, and a large, low, slanting orbital face (fig. 4, *pa.s.*, *f.*). In front the frontal dips into a thick *antorbital* process (figs. 1 & 4, *f.*), which is overlapped by the large nasal (*n.*).

This huge fibrous frontal is very *ichthyic*; it is divided into three processes in front, the antorbital and ethmoidal processes, the outer broad, and the inner sharp. In the very middle it is hollow, and from thence there run a small groove directly forwards, and a pair of deep grooves obliquely along the antorbital lobes. Behind there is a low thick ridge with crescentic scooping at its sides. Narrowing from the antorbitals it then sends out a short thick postorbital process; from that part the parietal region (*p.*) narrows, by steps, between the auditory masses, to overlie the occipital arch.

Half as much space is covered by the imbricating "nasal" wedges (*n.*); these are large, roughly triangular bones, with rounded corners and a notched outer margin; this notch, nearer the inner than the outer angle, is for the external nostril (*e.n.*). The nasals are gently convex above, and very fibrous. Running along their outer margin (figs. 1, 4, 7) we see under their edge the preorbitals (*p.ob.*) and the septo-maxillaries (*s.mx.*); the latter are now seed-shaped and flat, and bordered by the remains of the larger upper labial (*u.l.*); the former are flat, much larger than the septo-maxillaries, and ending behind in an inturned sharp hook. As the nasals meet above, in the front part (fig. 1, *n.*), so the premaxillaries meet below (fig. 2, *px.*); they, like the maxillaries (*mx.*), are entirely on the under surface. Together, the premaxillaries have the form of the letter W; they have each a pyriform outline, with a sharp stalk, the palatine process. A similar process grows from the maxillary (*mx.*), as this bone overlaps the premaxillary in front and joins it by a sinuous margin. The anterior part of the rounded and thickish outer edge of the maxillaries help the others to make a semicircular outline to the front of the face; but the maxillaries then bend in, and as gently bend out again where they have met the pterygoids. Their jugal process is a pointed spatula, which lies obliquely beneath the leafy part of the pterygoid, in its groove. The eyeball (*e*) just reaches, and a little overlies the junction of these bones (fig. 1). The "suborbital fenestra" is here finished in front by the maxillary; the cartilage is absorbed at that part.

The only important change to be looked for in the débris of the branchial arches would be the ossification of the thyro-hyal bar (Plate 60. fig. 7, *br.* 2, 3); this part had been removed in Professor HUXLEY'S specimen.

Concluding Remarks.

In the prosecution of this special kind of research I am under the necessity of keeping to the driest morphological details, making comparisons from time to time of like parts in diverse types.

It was a good day for this work when Professor HUXLEY resumed his researches in the Amphibia (winter of 1873–74), for that gave rise to a discovery of the errors in my former paper on the Frog's Skull. Finding him thus engaged, and receiving his criticism, I gladly took up the amphibian types again, working as much as possible in concert with him, and especially reexamining all those points on which we differed at that time.

The result has been all but unanimity; and my own mind is still open to further modification of views, when evidence of any unsafeness of deduction or of incorrectness of observation shall be forthcoming.

Professor HUXLEY has acknowledged to me the extreme arduousness of this kind of work, and we both agree that the Amphibia, and the Anura or Batrachia especially, are the most instructive, albeit they present the knottiest problem of all the Vertebrata.

At present I defer giving any special summary: in the beginning of the present paper I have thoroughly sifted my older work, and it need not be done twice over. Here it is seen that the Frogs differ in important things from the Toads; the Toads that have *a tongue* from the "aglossal" types; and that the two types of tongueless Toads differ from each other in many instructive particulars.

Ready to follow this paper is one which will treat of the stages of the Bull-frog (*Rana pipiens*) and the Paradoxical Frog (*Pseudis paradoxa*); but to these I wish to add the Tree-frogs, the Bombinator Toads, and sundry other types of Batrachia, to say nothing of the Salamandrian or "Urodelous" Amphibia.

In my former paper (p. 202) I spoke of the light that the Batrachian skull sheds on that of the Mammalia; surely that assertion is not in the least belied by what is here written concerning the *marsupial*, *gill-less* young of the Surinam Toad.

I am not unaware that this kind of labour may seem to be the mere heaping up of details; to speculative minds, certainties and systems are demanded from the first; such certainties and such systems end in doubt and scientific confusion.

But I believe that when certainty has been painfully attained (although it be through much doubt and long-continued research), then a *system* will grow spontaneously, as a real living thing, and not as a mere human fantasy.

All the confusion arising from my mistaken view of the early coalescence of the upper part of the hyoid with the mandibular pier is now gone, and the cartilage which was supposed to be segmented off from that adhering half-bar, is seen now to become the cartilaginous *ear-ring*.

The important discovery, by Professor HUXLEY, of the *late* appearance of the "columella" was extremely confusing to me at first; it is now used as a key to unlock the most difficult "wards" of these organisms.

It is evident that we have in the Batrachian hyoid arch that which lays its hand, as it were, upon the hyoid arch of both Fish and Mammal, and will soon explain both. Although the stapes is not *segmented out* from the ear-capsule of the "Anura" (though it is so formed in the "Urodela," but formed later), yet it is *periotic* in nature, a hypertrophied and chondrified tract of the perichondrium of the auditory cartilaginous wall, just where that wall thins itself and opens towards the vestibule.

It appears to me that *Dactylethra* and *Pipa*, and even the Common Toad, by not cutting off the "interstapedial" as a distinct cartilaginous segment, but merely differencing it as a large, *even the larger*, shaft-bone, have shown that their "columella" is made up of a proximal "hyomandibular" and a distal "symplectic."

The ultimate disposal of the large cartilages of the suctorial mouth of the Tadpole (the "labials") has made the interpretation of the nasal capsule easy; we now know what has budded out from the trabeculæ (there are no distinct "paraneural" cartilages to the nasal sacs in the Anura), and what has been superadded to the labyrinth by the cartilages of the oral ring, in their metamorphoses.

Now that we know the structure of the cartilaginous skull when it is first fairly a "chondrocranium," and that the two myotomic masses are not accompanied at first by paraneural cartilages, but that the apices of the trabeculæ cling to the apex of the notochord, distinct at first, and afterwards becoming confluent with the "paraneurals"—all these things, being true, will lead to further truth.

Some of these things were seen by Professor HUXLEY long ago in the Newt, and lately in the Axolotl; and by me afterwards, as the result of the most difficult demonstration ever made by me in the early larva of the Common Toad.

Finally I may remark that not "old experience," only, is helping us, but new and more delicate means and appliances in our method of research.

DESCRIPTION OF THE PLATES.

PLATE 54.

Rana temporaria.—*Adult*.

Fig. 1. Fore part of endocranium (partially ossified chondrocranium), seen from above. ×6 diameters.

Fig. 2. The same, lower view. ×6 diameters. (In this and the next figure the outer bones are faintly shown.)

Bufo vulgaris.—*Adult.*

Fig. 3. Endocranium, seen from above. ×4 diameters.
Fig. 4. The same, lower view. ×4 diameters.
Fig. 5. Part of the same cranium, seen from the front. ×4 diameters.
Fig. 6. Part of the facial region (ectocranium), with labial; side view. ×8 diameters.
Fig. 7. Auditory region of skull, with upper edge partly pared away. ×4 diameters.
Fig. 8. Columella and stapes from the same; inner view. ×8 diameters.

PLATE 55.

Bufo vulgaris.—*Tadpoles and young.*

Fig. 1. Chondrocranium of a Tadpole, 4 lines long; 1st stage; upper view. ×40 diameters.
Fig. 2. The same, side view. ×40 diameters.
Fig. 3. Chondrocranium of a Tadpole, $5\frac{1}{2}$ lines long; 3rd stage; upper view. ×35 diameters.
Fig. 4. Chondrocranium of a Tadpole, 5 lines long; 2nd stage; half of lower view. ×35 diameters.
Fig. 5. Chondrocranium of a Tadpole, 8 lines long; 4th stage; part of lower view. ×20 diameters.
Fig. 5^a. Part of same region of fenestra ovalis. ×200 diameters.
Fig. 6. Chondrocranium of young Toad, 5 lines long; 5th stage; part of inner view. ×15 diameters.
Fig. 7. Part of the same. ×45 diameters.
Fig. 8. A view, like fig. 6, of a young Toad, 8 lines long. ×15 diameters.

PLATE 56.

Dactylethra capensis.—*Youngest Tadpole, whose total length was* $1\frac{1}{3}$ *inch.*

Fig. 1. Upper view of Tadpole; 1st stage. ×4 diameters.
Fig. 2. Lower view of Tadpole. ×4 diameters.
Fig. 3. Side view of Tadpole. ×4 diameters.
Fig. 4. Chondrocranium of same, upper view. ×10 diameters.
Fig. 5. The same, lower view. × 10 diameters.
Fig. 6. Mandibles and hyoid cartilages of the same. ×10 diameters.

PLATE 57.

Dactylethra capensis.—*Tadpoles* $1\frac{2}{3}$ *inch long.*

Fig. 1. Chondrocranium of Tadpole, upper view, 2nd stage. ×6 diameters.
Fig. 2. The same skull, seen from below. ×6 diameters.

Dactylethra capensis.—*Tadpoles at their largest size.*

Fig. 3. Chondrocranium of Tadpole, upper view; 3rd stage. × 6 diameters.
Fig. 4. The same skull, seen from below. × 6 diameters.

PLATE 58.

Dactylethra capensis.—*Tadpole: young and adult.*

Fig. 1. Hyoid and branchial cartilages of one side, from below; 2nd stage. × 6 diams.
Fig. 2. Cranium of young *Dactylethra* with large legs and tail; 4th stage. × 10 diams.
Fig. 3. The same skull, seen from below. × 10 diameters.
Fig. 4. Mandible and hyoid of the same skull. × 10 diameters.
Fig. 5. Hyoid and branchial arches of the adult *Dactylethra*, upper view. × 3 diams.
Fig. 6. Mandibular ramus of same, inner view. × 3 diameters.

PLATE 59.

Dactylethra capensis.—*Adult.*

Fig. 1. Chondrosteous cranium, with roof-bones removed; upper view. × 3 diameters.
Fig. 2. The same, seen from below. × 3 diameters.
Fig. 3. The same, side view. × 3 diameters.
Fig. 4. The same, seen from behind. × 3 diameters.
Fig. 5. Endocranium, front part, seen from above. × 3 diameters.
Fig. 6. The same, lower view. × 3 diameters.
Fig. 7. Auditory region of same skull; inverted view, with dislocated "columella." × $4\frac{1}{2}$ diameters.
Fig. 8. Framework of auditory region; side view. × $4\frac{1}{2}$ diameters.
Fig. 9. Front view of quadrate region, with projecting parts removed. × $4\frac{1}{2}$ diameters.

PLATE 60.

Pipa monstrosa.—*Embryo $\frac{3}{4}$ inch long, and young (ripe), $6\frac{1}{2}$ to $7\frac{1}{2}$ lines long.*

Fig. 1. Embryo attached to yelk-mass; side view. × 5 diameters.
Fig. 2. The same; upper view. × 5 diameters.
Fig. 3. Chondrocranium of the same; lower view. × 15 diameters.
Fig. 4. Detached visceral arches of same; upper view. × 20 diameters.
Fig. 5. Chondrocranium of larger young *Pipa*; upper view. × 14 diameters.
Fig. 6. The same skull; lower view. × 14 diameters.
Fig. 7. Mandible and branchial arches of the lesser young *Pipa*; upper view. × 14 diameters.
Fig. 8. Section through nostrils of larger young *Pipa*. × 30 diameters.

PLATE 61.

Pipa monstrosa.—*Embyro and ripe young.*

Fig. 1. Orbital region of chondrocranium (embryo); upper view. × 20 diameters.
Fig. 2. Cranium of larger young *Pipa*; upper view. × 14 diameters.
Fig. 3. The same skull; lower view. × 14 diameters.
Fig. 4. Part of fig. 2; nasal region. × 42 diameters.
Fig. 5. The same, with investing bones removed. × 42 diameters.
Fig. 6. Part of fig. 2 (auditory region). × 42 diameters.
Fig. 7. Part of fig. 3 (ethmo-palatine region). × 42 diameters.

PLATE 62.

Pipa monstrosa.—*Adult.*

Fig. 1. Cranium; upper view. × 2 diameters.
Fig. 2. The same; lower view. × 2 diameters.
Fig. 3. The same; end view. × 2 diameters.
Fig. 4. The same; side view. × 2 diameters.
Fig. 5. Mandible; upper view. × 2 diameters.
Fig. 6. The same; side view. × 2 diameters.
Fig. 7. Fore part of skull, with investing bones in outline; lower view. × 2 diameters.
Fig. 8. Cranial elements of the same part; lower view. × 4 diameters.
Fig. 9. Temporal region of skull (part of fig. 4). × 6 diameters.

The *abbreviations* are the same in the present paper as in the last, with a few exceptions and a few additions. The terms "suprahyomandibular" (*s.hm.*) and "infrahyomandibular" (*i.hm.*) are dropped, as they were given under a misconception as to the nature of the parts. The first (*s.hm.*) has now to be lettered as the "annulus tympanicus" (*a.t.*), and the second (*i.hm.*) is known to be the pedicle of the mandibular pier (*pd.*). The special term "columella" (*co.*) is here added—also "preorbital (*p.ob.*), "prenarial ligament" or "lamina" (*p.n.l.*), "recurrent cartilage" or "lamina" (*rc.c.*), "otic process" (*ot.p.*), "thyroid gland" (*tr.g.*), "thymus gland" (*tm.g.*); the "quadrate *bone*" (*q.*) is here the "quadrato-jugal" (*q.j.*); the external valvular process of the nostril (*v.e.n.*) is here the "first upper labial" (*u.l.*).

In this paper the distal part of the "columella" is the "symplectic," and that term is erroneously applied to a part of the mandible in the former paper.

The nerves are also numbered somewhat differently, according to the new notation; the "portio mollis" is now the 8th, the "glossopharyngeal" the 9th, and the "vagus" the 10th.

XXV. *On determining the Depth of the Sea without the use of the Sounding-line.*

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INTRODUCTION.

IT occurred to me some years ago that the inferior density of sea-water as compared with solid rock, such as that composing the crust of our earth, might be taken advantage of to devise a method of determining the depth of sea below a vessel. If an instrument could be constructed which, when suspended on board ship, would indicate extremely slight variations in the total attraction of the earth, those indications might be referable to the depth of sea, and a scale be obtained whose divisions would give the depth in fathoms, or other units, without having recourse to the laborious process of sounding by means of the sounding-line.

Terrestrial Attraction: NEWTON.—Our knowledge regarding terrestrial attraction dates from NEWTON, who proved that "the attraction of a spherical shell on an external particle is the same as if the mass of the shell were collected at the centre," and that the earth might be considered as consisting of an aggregate of such shells. Bearing in view, however, the fact of the earth's rotation he proved its ellipticity, and that partly in consequence of that form, and partly on account of the centrifugal force engendered by its rotation, the total attraction of the earth in reference to a point on its surface must vary with latitude[*]. He determined the ratio of increase on the supposition that the earth is homogeneous, and showed that it varies as the square of the sine of the latitude. It is actually represented by the formula

$$g=g'(1+\cdot005133\sin^2\lambda),$$

in which g signifies gravitation at a place in latitude λ, and $g'=32\cdot088$ gravitation at the Equator.

Recent Researches: STOKES *and* AIRY.—The recent researches by STOKES and others have shown that these determinations are correct only approximately, and that the actual total attraction of the earth at any one point, even if taken upon the sea-shore, is influenced by the rising land of continents, or by cavities in the interior of the earth. He also established a reason for an observation made previously by AIRY, that total gravitation is greater on an island than it is near the sea-shore of a continent, and greater on the sea-shore than on an estuary inland[†].

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[*] NEWTON'S 'Principia,' Book iii. proposition xx. problem iv.

[†] Cambridge Philosophical Transactions, vol. viii. pp. 672–695.

Employment of Seconds' Pendulum.—The seconds' pendulum has been the instrument employed in all cases to determine variations in the total attraction of the earth upon its surface, this being the method first proposed and adopted by NEWTON.

Spiral Spring proposed by HERSCHEL.—Sir JOHN HERSCHEL has proposed to use instead of the pendulum a weight attached to a spiral spring, and he has shown that with increase of the force of gravitation, the spring must be proportionately elongated. Sir JOHN HERSCHEL writes, that "the great advantages which such an apparatus and mode of observation would possess, in point of convenience, cheapness, portability, and expedition, over the present laborious, tedious, and expensive process, render the attempt to perfect such an instrument well worth making"*. It appears, however, that this proposal by Sir JOHN HERSCHEL has never been practically realized, and that, indeed, no serious attempt has been made to construct an instrument of such delicacy as to show statically minute variations in total gravitation, notwithstanding the great oscillations to which a weight so suspended would be liable, and notwithstanding the influence of changes of temperature and atmospheric density.

General Conditions.—Neither the pendulum nor the apparatus suggested by Sir JOHN HERSCHEL would be applicable to the measurement of the height of a mountain or plateau above the sea-level, owing to the considerable error which would be caused by changes in gravitation, through the local attraction of the mass of the mountain itself above the horizon, nor would either instrument be serviceable on board ship for obvious reasons. But if an instrument could be devised which would be capable of indicating extremely slight variations in the total gravitation of the earth, subject only to comparatively slight causes of error, it would be found, I contend, that these indications would vary with the varying depth of water below the instrument, in such a definite ratio as would render it possible to construct a working scale, the divisions of which would represent depth of water.

Attraction influenced by Depth of Water: General Statement.—The reason why the total attraction upon the surface of the ocean must be less than on the shore, is evident from the fact that the density of sea-water is nearly three times less than that of such calcareous, siliceous, and aluminous rocks as constitute the principal portion of the crust of the earth; and it is also evident that, although the total mass of the earth and the distance of the instrument from its centre remains the same in gliding along the liquid surface of the sea, the total gravitation must be influenced in a greater measure by the mass near at hand, and that in proportion to the thickness of the layer of the substance of inferior density the total gravitation must be affected.

Ratio of decrease of Gravitation with Depth.—The ratio of decrease depends, in the first place, upon the ratio of the density of sea-water to that of solid rock. The mean density of sea-water may be taken at 1·026, and the density of the rock composing the crust of the earth may be taken to be the mean of the following densities:—

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* HERSCHEL's 'Astronomy,' Cabinet Cyclopædia, footnote p. 125.

Mountain Limestone	2·86
Granite	2·63 to 2·76
Basalt	3·0
Red Sandstone	2·3 to 2·52
Slate	2·8 to 2·9

Average density of above 2·763 nearly.

It is dependent, in the second place, upon the total gravitation of the earth in reference to a point on its surface, and upon the influence exercised in that general result by the strata of matter in the immediate vicinity of that point.

Mathematical Investigation.—In Plate 63. fig. 1 the circle represents the circumference of the earth, which I propose to consider for the present irrespectively of its rotation, and as being spherical and of uniform density.

Let P be the point upon the surface of the globe where the attraction is to be measured; then, in order to calculate the amount of variation that will be produced in the total attraction of the earth, supposing it to be of uniform density, by a given depth of water below the attracted point P, a line is drawn from that point to the centre of the earth, and the same is divided into an unlimited number of indefinitely thin slices, by planes perpendicular to that line.

In taking one of these slices at the distance h from the attracted point, an expression is obtained representing its aggregate attraction, thus—

The slice is composed of concentric rings of sectional area

$$dh\,.\,dx=dh\,.\,z\,.\,d\alpha : \cos\alpha,$$

and of the capacity

$$2\pi\,.\,z\,.\,\sin\alpha\,.\,dh\,.\,z\,.\,d\alpha : \cos\alpha,$$

which gives

$$\frac{2\pi\,.\,z\,.\,\sin\alpha\,.\,dh\,.\,z\,.\,d\alpha}{z^2}$$

as the differential of the attraction, where z and z in the numerator and z^2 in the denominator, although variable quantities, always vary together, or

$$ddA_1=2\pi\,.\,dh\,.\sin\alpha\,.\,d\alpha.$$

This expression has to be integrated between the limits of h and 0, and α and 0; thus

$$\int_0^h\int_0^\alpha 2\pi\,.\,dh\,.\sin\alpha\,.\,d\alpha=\int_0^h 2\pi dh\int_0^\alpha \sin\alpha\,.\,d\alpha=2\pi\int_0^h dh\,(1-\cos\alpha).$$

Since

$$\int_0^\alpha \sin\alpha\,.\,d\alpha=1-\cos\alpha,$$

also

$$\cos\alpha=\frac{h}{z}=\frac{h}{(x^2+h^2)^{\frac{1}{2}}}=\frac{h}{\{(2\mathrm{R}-h)h+h^2\}^{\frac{1}{2}}}=\frac{h}{\sqrt{2\mathrm{R}h}}=\frac{h^{\frac{1}{2}}}{2\mathrm{R}^{\frac{1}{2}}},$$

$$\therefore 2\pi\int_0^{\mathrm{h}}dh\,(1-\cos\alpha)=2\pi\int_0^{\mathrm{h}}\left(1-\frac{\sqrt{h}}{\sqrt{2\mathrm{R}}}\right)dh=2\pi h-2\pi\int_0^{\mathrm{h}}\frac{\sqrt{h}}{\sqrt{2\mathrm{R}}}\,dh$$

$$=2\pi h-2\pi\frac{1}{\sqrt{2\mathrm{R}}}\cdot\tfrac{2}{3}\cdot h^{\frac{3}{2}}=2\pi h\left(1-\tfrac{2}{3}\sqrt{\frac{h}{2\mathrm{R}}}\right)=\mathrm{A}_1 \quad \ldots\ldots \quad (1)$$

is the total attractive force exercised by the uppermost portion of the globe to the depth h.

For small values of h, the expression $\sqrt{\frac{h}{2\mathrm{R}}}$ may be neglected, and the formula may be written

$$\mathrm{A}_1=2\pi h. \quad \ldots\ldots\ldots\ldots \quad (2)$$

In substituting 2R for h in formula (1) we obtain

$$\mathrm{A}=\tfrac{4}{3}\,\mathrm{R}\,.\,\pi,$$

the expression for the total attraction of the earth, which was determined by NEWTON; a verification is thus furnished of the correctness of the above calculation.

The proportion between the attraction exercised by the upper segment and the whole earth, supposing them to be composed of uniform material, is therefore as

$$\mathrm{A}_1:\mathrm{A}=2\pi h:\tfrac{4}{3}\mathrm{R}\pi$$

or as

$$h:\tfrac{2}{3}\mathrm{R}.$$

Ratio of variation of Attraction, as the depth to the Earth's radius.—If sea-water had no weight, the total force of gravitation at the point P would be diminished in the ratio

$$\frac{\text{depth of sea}}{\frac{2}{3}\text{ radius}};$$

but, inasmuch as the ratio of the difference of mean rock and sea-water to mean rock is

$$\frac{2{\cdot}763-1{\cdot}026}{2{\cdot}763}=\frac{1{\cdot}737}{2{\cdot}763},$$

it follows that the real influence of depth, on the supposition of the earth's density being throughout that of mean rock, would be represented by the expression

$$\frac{\frac{1{\cdot}737}{2{\cdot}763}h}{\frac{2}{3}\mathrm{R}}=\frac{h}{\frac{614}{579}\mathrm{R}}=\frac{h}{1{\cdot}06\,\mathrm{R}},$$

or approximately as the depth to R.

Thus, for a depth of one thousand fathoms, gravitation diminishes by $\frac{1}{3691}$ of itself.

Necessity for modifying result, neither compression great enough to be sensible in its *effect, but the two not equal.*—The rock composing the crust of the earth will be under compression, and therefore denser at the depth corresponding to the depth of sea; but sea-water itself will increase in density with depth in a somewhat similar ratio, so that the comparison between sea-water and solid rock remains virtually the same for all depths. The greater density of the earth towards its centre will, however, greatly influence the measure of this dependence as established by the foregoing calculation; but in constructing a measuring instrument it will be safer to rely upon the result of actual measurement, in the absence of reliable information regarding the increase of density towards the centre, by comparing its indications with those obtained by means of the sounding-line. It may here be remarked, however, that the indications of variation of gravitation with variation in the depth of water, which have been obtained by the use of the instrument, show in excess of what the above calculation gives with the mean density of the rock composing the crust of the earth as a factor, and agree more nearly with what would result if the upper strata of the earth were of a density equal to the mean density of the whole earth. Actual observations, as given in the Table further on, confirm, in a remarkable degree, the arithmetical ratio of decrease of gravitation by depth which results from the foregoing calculation.

First attempt to construct a Bathometer.—Several years ago I constructed an instrument in which the gravitation of the earth was represented by a column of mercury in a glass tube closed at its upper end, and resting upon a cushion of air enclosed in a large bulb, which air, when kept at a perfectly uniform temperature, represented uniform elastic force unaffected by gravity or atmospheric density. The principal difficulty that presented itself in designing a workable instrument on this principle, consisted in obtaining a scale sufficiently large to show such extremely slight variations in the total gravitation of the earth as would result from ordinary variation in the depth of water. From the calculation given under the previous head, assuming the mercury column to have a height of 760 millims., each fathom of depth of water would represent a variation of potential force in that column equal to a height of ·0002059 millim., a quantity which it would be impossible to show on any scale. A scale would in reality not even realize this quantity of decrease in the upper surface of the column, because a portion of the adjustment of height would take place in the air-bulb below, partly from the rise of mercury into the bulb, and partly through increase of pressure of the imprisoned air due to its compression. I succeeded, however, by means of an arrangement of the instrument with three liquids of different densities, in increasing the effect of a change of gravitation upon the mercury column three hundredfold, whereby a change of 10 fathoms depth would be represented by a movement of ·6177 millim. of the boundary between the two liquids in the vertical tube, a quantity sufficiently large to be appreciated in the divisions of a scale. This instrument is shown in Plate 63. fig. 2.

Tests of Instrument.—This instrument was tested by me in 1859 on board H.M.S. 'Firebrand,' commanded by Capt. Dayman, during a trip undertaken for the Admiralty for the purpose of determining a line of soundings across the Bay of Biscay, with a view to the establishment of a submarine cable: it proved successful to the extent that I was able to predict, approximately, the depth that would be found on the use of the sounding-line. The difficulty, however, of observing the instrument was great, owing to the excessive pumping-action, the consequence of the oscillations of the ship, as well as to the difficulty of obtaining perfect uniformity of temperature. The method of observation pursued was to take series of ten observations of alternate maxima and minima positions of the film, or boundary line between the liquids, of which the mean was taken to be its true position upon the instrument; but occasionally oscillations of extraordinary amount occurred, tending to vitiate the value of even these means. The instrument was both bulky and delicate, and it was found impracticable at the time to provide the ship with a sufficient store of ice (to be used in maintaining the instrument at a uniform temperature) to last during a lengthy voyage. In consequence of these drawbacks, I relinquished for a time the idea of constructing a reliable bathometer.

Present construction of Bathometer.—Last year the practical difficulties encountered in laying submarine cables in water the depth of which had not been accurately ascertained beforehand, revived in me the conviction that an accurate instrument would be of considerable value, not only to the cable-layer but to the navigator generally, when unable to determine his position astronomically. In the instrument about to be described, the mercury column is retained as the representative of the force of gravitation, but the balancing force is obtained through two spiral steel springs, which are so adjusted to the force of the mercury column that changes of temperature are entirely eliminated from the result.

The instrument, which is represented on Plate 64, consists of a tube of steel, with cup-like extensions at the two extremities, which is suspended in a vertical position from a universal joint, at some little distance above the centre of gravity of the system, with a view of preventing pendulous action.

The upper cup-like extension of the tube is closed with a lid, provided with a closed stopper, which is screwed down when the instrument is not in use, and released for the access of atmospheric pressure shortly before observations are about to be taken. The lower portion is closed by means of a thin diaphragm of corrugated plate of steel, similar to the corrugated plates used in the construction of aneroid barometers. The centre of the diaphragm rests upon a crosshead, to which two carefully tempered steel springs are attached, which pass upwards on opposite sides of the mercury column, and are held at their upper extremities by adjusting-screws in the sides of the upper cup. The neck of the vertical pipe where it opens out into the upper cup is nearly closed by means of a disk or stopper of steel, perforated by a hole of only ·2 millim. diameter, the object being to reduce the pumping-action on board ship to a minimum. Before screwing-in this stopper the tube is filled with boiled mercury up to about the middle of the upper cup.

Available Force.—The mercury column represents the potential of force resulting from the area of the lower cup, multiplied into the height of column and the density of mercury.

The instrument of which the results have been chiefly recorded in the Table given further on has cups of 90 millims. in diameter and a height of mercury of 600 millims., representing an available force of 51·9 kilogrammes susceptible to variation in gravitation; whilst the instrument of which the drawing is given has cups of 50 millims. diameter and a mercury column of 500 millims., representing an available force of 13·35 kilogrammes. These amounts are amply sufficient to overcome by their variations any slight frictional resistance in the liquid column or in the diaphragm. But this frictional resistance is really eliminated from consideration by oscillations of the vessel, which cause certain pumping-action (kept within narrow limits by the contracted orifice), and bring the diaphragm into the true mean position, notwithstanding slight frictional resistances.

Range of Scale.—Under this head we have to consider what will be the effect on the instrument by a given change in the total attraction. Assuming a diminution of gravitation equal to say $\frac{1}{370,000}$, representing about 10 fathoms of depth, this would be equalized by a reduction in the height of column of $\frac{600}{370,000}$ millim. $= \cdot 00162$ millim. The column of mercury in rising under this changed condition of equilibrium will, however, not become shortened, as in the case of the barometer when affected by a diminution of atmospheric pressure, or as was the case in the instrument before described, but for every fraction of a millimetre which the top level rises the centre of the diaphragm will rise also, and in an increased ratio, depending upon the proportion of the diameter of the solid central portion of the diaphragm to the diameter of the cup. If the central solid part of the diaphragm was only a point, it is easy to see that for every fractional rise of the mercury in the upper cup the centre of the diaphragm would rise three similar fractions, and the real height of the mercury column would diminish two fractions instead of increasing one. But in reality the central portion of the diaphragm is so proportioned to the cup, that for a rise of one increment of height of mercury the centre of the diaphragm would rise to about double that amount, and the effectual height of the mercury column would decrease instead of increasing to the amount of readjustment required. If the elastic range of the springs balancing the pressure of the mercury were equal to the height of the mercury column, the increase of height on the one hand would be exactly balanced by the increase of elastic force on the other, and the instrument would be in a condition of unstable equilibrium, similar to that of a balance-lever suspended at its centre of gravity. If, on the other hand, the elastic range of the springs were equal to one half the height of column, the increase of elastic force would proceed at double the rate of the increase of potential of the column, and the result would be a scale proportionate to the simple height of column.

It follows from this that the elastic range of the springs must be less than the length of the mercury column. In the actual instrument the elastic range of the spring exceeds to some extent half the length of the column, so that one division of the instrument represents less than its seeming proportion of the total gravitation. It would be difficult to determine the actual scale of the instrument *à priori*; and I therefore adopted the easier and safer method of relying for its final adjustment upon the result of actual working. The limits to the sensitiveness of action of the instrument are chiefly imposed by the diaphragm itself, which must be maintained near its neutral position, because its elastic range is limited and discordant with the range of the spiral springs. It is desirable on this account to make the diaphragm of as thin and flexible metal as possible, and to make the annular indentations as deep as they can be made. This consideration led me to try a diaphragm of silk impregnated with solution of india-rubber, which diaphragm has the advantage of being more flexible than one made of metal, but is liable, on the other hand, to stretching under the constant pressure of the mercury. A diaphragm of thin steel plate has been found to be sufficiently flexible for the purposes of the instrument.

It was desirable to avoid levers, pulleys, and other such working parts in the instrument, which parts are liable to derangement from stretching, bending, and abnormal expansion, which would make the instrument liable to change its zero position. I have therefore had recourse to a micrometer-screw with electrical contact, which, with great solidity and simplicity of parts, affords the advantage of a long and accurately divided scale.

Reading of Bathometer.—The micrometer-screw passes vertically through a boss below the centre of the diaphragm, which is attached to the tube by means of two insulating supports of ebonite. A galvanic battery is connected through one pole to the body of the tube, and by the other to the boss through which passes the micrometer-screw. An alarum or galvanometer is comprised in the electrical circuit, which is closed whenever the end of the micrometer-screw touches the extreme point of the crosshead supporting the centre of the diaphragm, and therefore the weight of the mercury column. The galvanometer and alarum are so constructed that one element is sufficient to produce the signal, as, if a number of elements were employed, discharges of currents would ensue and affect the surfaces of electrical contact. It is important to clean these surfaces from time to time, by passing a sheet of stout paper or of fine emery-paper between them. A graduated circle is provided to indicate the precise angle through which the micrometer-screw is moved from its zero position when its point touches the end of the crosshead, an event marked by the sounding of the alarum or motion of the galvanometer-needle. The points of contact on the crosshead and on the micrometer-screw are made of platinum in the usual way; but the contact-piece carried by the screw is attached to the same through the medium of a strong and short horseshoe spring, the object of which is to soften the contact between the two points, and thus allow of the natural oscillations of the weighty column as influenced by the motion of the vessel. The pitch of the micrometer-screw being 5 millims. nearly, and the graduated circle being divided into 1000 equal parts, it follows that each division of the scale through which the screw is turned raises the contact-point ·005 millim., a quantity which is intended to represent the depth of a fathom. The micrometer-screw is turned by a wheel geared into a pinion, which is brought up to a place near the point of suspension of the instrument, where it can be turned by means of a milled-head, without the observer being inconvenienced by the oscillations of the instrument relatively to the vessel. Instead of two spiral springs three might be applied, dividing the circle equally, probably with some advantage, viz. that of imparting additional steadiness to the crosshead in its horizontal position. The letters of reference on the drawing, with the references given below, sufficiently describe the mechanical details of the instrument. It remains to be shown how an instrument answering to this description can be depended upon for giving true indications of the varying depths of water below the same, notwithstanding changes of temperature, of atmospheric pressure, and of geological formation and condition of the bottom of the sea.

Influence of Temperature.—In considering the influence of temperature upon the instrument, it was necessary to investigate its action upon the component parts separately. The effect of temperature upon the linear dimensions of mild steel, of which the instrument is mainly composed, is sufficiently well known. Steel expands, according to the experiments of DULONG and PETIT, ·000012 of its length for every degree Cent. rise of temperature between 0° and 100° C.; and this number agrees closely with experiments by REGNAULT, who found the cubic expansion of mercury to be ·00018153 per degree C., between 0° and 100° C.; in both these metals the ratio of expansion by heat may be considered as strictly arithmetical between ordinary limits of temperature.

Influence of Temperature on Steel Springs.—Regarding the influence of temperature upon the elasticity of springs, we have investigations by M. G. WERTHEIM*, which show a diminution of elasticity with rise of temperature in all metals except iron. This latter metal attains its maximum elasticity (according to this author) at 100° C.; but annealed cast steel agrees with gold and silver and other metals in showing a diminution of elasticity with rise of temperature. The results given in the table prepared by M. WERTHEIM show a coefficient of diminution of elasticity for cast steel of ·00033768 per degree Centigrade, the modulus of elasticity at 0° C. being 19561, and at 80° C. 19014. Before the bathometer was set up, I had experiments made on the variation of the elasticity of its spiral steel springs in the range of ordinary temperature, which proved this important result,—that the elastic force of well-tempered steel springs diminishes with increase of temperature, within the limits of ordinary temperature, in an arithmetical ratio. The coefficient which I obtained from these experiments was ·000258 of diminution of elasticity per degree Centigrade rise of temperature; and the small difference between this and the coefficient deduced from WERTHEIM's table will be due most likely to a difference of temper in the steel.

In the bathometer the linear expansion of the springs is compensated by the linear expansion of the tube to which they are attached; and we have therefore only to deal with the variation of elastic force which has to be compensated for, in order to make the indications of the instrument independent of temperature.

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* Annales de Chimie et de Physique, sér. 3, 1845, xv. 119. "Sur l'influence des basses températures sur l'élasticité des métaux."

Compensation for Temperature-effects.—The means of such compensation is provided in the mercury column. If this column were to consist of a plain cylindrical vessel, not subject to change in diameter by temperature, it is evident that its pressure upon the diaphragm would be the same whatever the temperature of the mercury might be; for with increase of temperature the height of the column would increase, and the density of the mercury decrease in precisely the same degree: such a column might be called one of *uniform potential*, and would not afford the means of compensation here desired. If, on the other hand, the column were made to consist of two shallow cups at top and bottom, connected by a tube of such diameter that its area, compared with that of the cups, might be neglected in calculation, it is evident that the potential of such a column would vary with the temperature in the ratio of the dilatation of mercury; in other words, the absolute height of the column would remain practically the same at all temperatures, whereas the density of the mercury would vary in the well-known ratio of ·00018153 per degree C. If a spring could be found whose ratio of variation was less than that required for the mercury, it is evident that between these extreme forms one might be found in which the two ratios of variation would be exactly alike. The ratio of variation of the steel springs depends upon their degree of hardness; and in the case of the instrument here referred to it amounted to ·000258, or was in excess of the compensating power furnished by the mercury. Complete compensation could therefore in this case not be obtained, although the remaining error is extremely small, and was rendered practically inappreciable by allowing the comparatively inelastic diaphragm to take a portion of the mercurial pressure.

The proportion, as resulting from calculation, would at any rate have to be modified in order to allow for the linear expansion of the steel composing the tube as affecting its capacity; but this expansion proceeding also in an arithmetical ratio will only affect to a small extent the precise relative diameter to be given to the tube, without in any way disturbing the ratios of arithmetical increase upon which the compensation of the instrument is based. An easy verification of this arrangement, which may be called a *parathermal system of adjustment* between gravitation and elastic force, is furnished in suspending the complete instrument in the hot-air chamber in which the experiments for variation of elasticity were made, when the variations of temperature gradually and artificially produced within the chamber should remain without effect upon its reading.

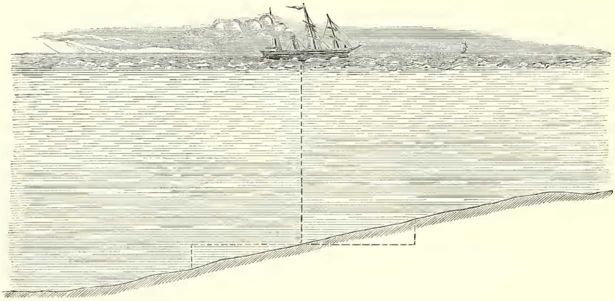
On subjecting the first instrument constructed on this principle to this test, a variation was discovered amounting to ·00000125 per degree C., which was not corrected, however, in trying the instrument on board the steam-ship 'Faraday;' and the results then obtained, and given below, have had to be adjusted to this extent for variation in temperature.

Influence of variation in Atmospheric Density.—The atmosphere presses equally upon the surface of the mercury in the upper cup of the bathometer and upon the diaphragm below, and variations in the height of the barometer, therefore, exercise, *per se*, no influence upon the instrument; but inasmuch as the mercury column exercises a preponderating gravitating influence only in the measure of its superior density to the atmosphere which the mercury replaces in the tube, it follows that changes in atmospheric density must exercise an influence upon the readings of the instrument. The atmospheric density depends upon barometric pressure, temperature, and admixture of aqueous vapour, the amount of which can be easily ascertained by readings of the dry- and wet-bulb thermometers and the barometer at the time of taking the bathometrical observations. These corrections have been made and applied to the observations taken on board the steam-ship 'Faraday;' the readings, however, having been taken at sea, the air was regarded as saturated with vapour, and the tension of the vapour at the temperatures has been employed. In ordinary usage of the instrument these corrections might be neglected without serious error, or a table might be constructed giving the amount of these corrections for observed changes of the barometer and thermometer.

Geological Influences.—The readings of the bathometer depend upon the inferior density of sea-water as compared with the solid constituents composing the earth's crust, which have been taken, in the calculation at page 673, as 2·763. No account was taken, in assuming the above average density of the earth's crust, of the presence of denser materials, such as metallic ores, heavy spar, &c., on the one hand, or of subterranean cavities on the other. But these abnormal occurrences are not frequent on dry land, being chiefly confined to mountainous districts, and may be assumed to be of less frequent occurrence in the great depressions constituting the sea-basins. Their relative effect upon total gravitation, as measured upon the surface of the water, is less, moreover, than it would be if measured upon the solid surface, on account of their greater distance from the instrument. The uniform density of the sea is an element eminently favourable to the attainment of uniform indications on its surface.

Geographical Influences.—The configuration of the bottom of the sea below the instrument must also exercise a sensible influence upon its readings. The instrument would not indicate, for instance, the existence of a local depression surrounded by elevated ridges or plateaux, nor would it indicate the existence of a peak. Considerable variations must therefore be occasionally expected between the readings of this instrument, however correctly adjusted, and the results of actual soundings; but it may be observed that broken ground, such as would cause these differences, is comparatively rare below the sea, which deepens gradually from the land in such a way that the contour lines of uniform depth can generally be distinctly traced; and the principal value of the instrument would consist in its indicating its passage above varying depths. The indications of the instrument must coincide very nearly with those of a sounding-line upon an even slope, because the comparative proximity of the ground towards the rise of the slope will be balanced by the absence of solid matter towards its descent, as will be apparent from the accompanying sketch (p. 682).

Attention has already been called to Sir George Airy's observation of the greater apparent gravitation on islands than on the sea-shore, and there than inland, and also to Professor STOKES's explanation of the matter. The working zero of the bathometer may be taken as a maximum or island indication; and the diminution due to the depth of water is therefore not influenced by the irregularities met with on solid land, in consequence of the matter raised above the natural surface of the sea. It has, however, been shown by Archdeacon PRATT and others that continents exercise an influence upon the level of the sea, that level being raised up towards the masses piled above the surface; and such disturbance of the natural water-level must necessarily exercise an influence upon the readings of the instrument. But this influence would be perceptible only in estuaries or upon the sea-shore of a mountainous continent, and may be neglected in dealing with the surface of the sea under all ordinary circumstances.



The more important disturbing cause affecting the instrument under this head is that of the ellipsoidal form of the earth and the varying centrifugal tendency on its surface, to which reference has already been made.

Effects of Latitude.—The determinations of the effect of latitude upon gravitation as made by NEWTON, CLAIRAUT, M'LAURIN, and others have already been alluded to, and it is important that the influence of this disturbing cause upon the instrument should be accurately ascertained in order that allowance may be made for latitude in its ordinary use. In order to test separately the effect of latitude upon the instrument, its indications were taken on the 8th of December at Westminster, lat. 51° 31′ N., long. 0° 7′ W., and afterwards at Brighton, lat. 50° 50′ N., long. 0° 10′ W., which is nearly due south of Westminster 41 nautical miles. At Westminster the indications were

Bathometer.	Barometer.	Thermometer. ° Fahr.
2 turns 432	30·425	43·4
431	30·425	43·6
430	30·425	43·4

These readings were taken at intervals of 5 minutes. The instrument was then carefully packed and removed to Brighton, where it was again set up. The first reading was taken an hour after arrival, and the readings taken during the afternoon are noted below.

	Bathometer.	Barometer.	Thermometer. ° Fahr.
From	2 turns 449·5	30·315	40·5
12.55 to	449	30·315	40·5
1.10 P.M.	451·5	30·32	41
From	2 turns 449·5	30·31	42·8
1.44 to	448·8	30·31	42·8
2 P.M.	449·5	30·31	42·8
From	2 turns 449·7	30·3	43·4
4.13 to	449	30·29	44
4.30 P.M.	449·5	30·29	44

The readings of the instrument taken the next morning at Westminster were—

2 turns 440	30·42	43
439·5	30·42	43·25
440	30·42	43·2

It will be found that, on correction being made for variation of temperature and atmospheric density, and taking the mean of the several readings (the first observed Westminster indications being taken as the standard), the above indications may be reduced to the following:—

	Bathometer.
Before leaving Westminster	431
At Brighton	452
On return to Westminster	439·25

Taking the mean of the Westminster readings, there would be a difference on the scale of 17 divisions, equivalent to a diminution in attraction of ·0000046, whereas calculation gives a difference of ·000066.

I have not succeeded in finding a satisfactory explanation of this apparent anomaly, which can hardly be attributable to defects of the instrument or to errors in observation, because on taking the instrument on board the steam-ship 'Faraday' from the Thames down the Channel, the variations observed (as recorded in the Table, page 684) accord very fairly with the increasing depth of water, but give no evidence of the great variations in total gravitation due to differences in latitude. In order to test the influence of latitude further, I caused the instrument to be taken to Scarborough, which is 207 miles north of Westminster; and the observations there taken confirmed generally those of Brighton, in showing insufficient variation, although their absolute value was rendered unreliable by an accidental disturbance of the instrument in transit.

It must be borne in mind that both Brighton and Scarborough are on the sea-shore, and that Westminster is upon an inland estuary, which circumstance would exercise an influence in the direction of equalizing the total gravitation at Brighton and Westminster.

Actual trial of the Instrument on board ship.—The foregoing may suffice to show what are the disturbing influences to be met with in the use of the instrument which forms the subject of this paper; but it was important to ascertain what would be the actual indications of the instrument in taking it on board ship over seas of varying and known depth, in order to compare the indications of the instrument with those of the sounding-line. For this purpose two instruments, the smaller of which is represented in Plate 64, were placed on board the steam-ship 'Faraday.' They were suspended in a closet adjoining the electrician's room, near the centre of motion of the vessel, and were observed carefully in Victoria Docks before starting, continuously during the voyage, and on the return of the vessel from Nova Scotia, where it had been sent for the purpose of reuniting the Direct United States Submarine Cable, which had been fractured, where it crossed the Newfoundland Bank, by the dragging of an anchor. The observations during this first trial of the instrument were made by Dr. HIGGS, the chief of the Electric Staff accompanying the expedition. The following Table gives the results of these observations.

TABLE I.—Bathometer Record: Steam-ship 'Faraday,' October 1875.

Date.	Hour.	Position.	Thermometer.	Barometer.	Bathometer Divisions.	Depth.
			° F.			fathoms.
Oct. 15.	Noon.	Victoria Docks	64·5	29·7	Zero.	2
18.	Noon.	Tidal Basin	65	29·95	3·5	
19.	8 A.M.	Lower Fort, Tilbury ...	60	30·00	9·0	
19.	10.35 A.M.	Off Southend	59	29·7	11·5	
21.	11.45 A.M.	Off Lizard	60	29·6	47·5	
22.	9 A.M.	....	56·3	29·5	92·5	
23.	Noon.	51° 0′ N.; 14° 37′ W. ...	Bad	weather.		By Chart.
25.	Noon.	51° 25′ N.; 26° 25′ W. ...	56	29·15	2130	1900
26.	Noon.	51° 7′ N.; 31° 14′ W. ...	56	29·75	2600	2000
27.	Noon.	Dead Reckoning	56	29·15	2870	2100
28.			Bad	weather.		

In this Table no correction for latitude has been made; and although the differences of latitude are not very great, they would nevertheless be more than sufficient to swamp the results of such minute differences of depth as are met with, for instance, in passing from the Thames down through the Channel. The concordant results shown in the Table seem to prove either that the correction for latitude is (for some reason, which, as already stated, I am not able to explain) much less in this instrument than it would be in the case of pendulum indications, or that the reading of the instrument had not been taken with a proper degree of care. It might be assumed that the known depths of the channel might have betrayed the observer involuntarily into a mistake when observing only small divisions on the instrument, although I must personally dissent from such a supposition, because I entertain the highest opinion of the conscientious

Table II.—Record of Bathometer readings compared with soundings taken on board the steam-ship 'Faraday,' October and November 1875.

Date.	Hour. G. M. T.	North Latitude.	West Longitude.	Thermometer.	Barometer.	Bathometer Divisions uncorrected.	Corrections for variations in Temperature and Atmospheric Density.	Bathometer Divisions corrected.	Sounding. Fathoms.	Difference.
	h. m.	° ′ ″	° ′ ″	° F.	″		(−)			
Oct. 29.	3 0 P.M.	47 50	47 0	56	29·5	216	14·55	201·45	197	+ 4·45
29.	8 55	47 34	48 23	57	29·7	113	13·5	99·5	100	− 0·5
30.	1 52 A.M.	....	......	58	29·5	74	10·95	63·05	54	+ 9·05
31.	12 0 P.M.	....	......	57·5	30·05	96	13·7	82·3	82	+ 0·3
31.	1 8	45 5	54 28	58	30·05	231	12·85	218·15	204	+ 14·15
31.	2 20	....	......	60	30·05	87	9·15	77·85	69	+ 8·85
31.	2 59	....	......	59·5	30·05	66	10·2	55·8	54	+ 1·8
31.	3 27	45 9 45	54 14	60·5	30·9	66	11·2	54·8	54	+ 0·8
31.	5 47	45 10 42	54 18 20	57·5	30·7	66	15·9	50·1	56	− 5·9
31.	7 27	45 11 15	54 17 53	56	30·7	66	18·55	47·45	54	− 6·55
Nov. 1.	12 15	45 10 12	54 18 25	55·5	29·5	66	15·7	50·3	58	− 7·7
1.	2 18	45 7 15	54 21 30	55	29·0	82	15·65	66·35	69	− 2·65
1.	3 25	45 6	54 22 48	60·5	28·9	87	4·6	82·4	73	+ 9·4
2.	12 50	....	......	59	28·78	63	6·85	56·15	47	+ 9·15
2.	2 58	....	......	55	28·9	63	14·35	48·65	46	+ 2·65
2.	5 30	....	......	60·5	29·0	85	4·9	80·1	69	+ 11·1
3.	7 57	45 5 48	54 25 42	58·5	29·3	120	9·4	110·6	100	+ 10·6
3.	9 20	45 4 50	54 28 34	58	29·5	226	10·95	215·05	200	+ 15·05
4.	2 10	45 10 36	54 20 6	57·5	29·7	82	12·5	69·5	64	+ 5·5
5.	12 35	....	......	57	30·0	95	14·5	80·5	80	+ 0·5
5.	1 45	....	......	58·5	30·0	98	11·8	86·2	86	+ 0·2
5.	4 16	....	......	58	30·0	90	21·65	68·35	76	− 7·65
7.	5 19	46 45	47 17	58	29·7	400	11·65	388·35	353	+ 35·35
7.	6 35	46 35	46 57	58	29·8	811	11·95	799·05	698	+101·05
7.	9 50	46 26	46 20	58·5	29·9	617	9·4	607·6	503	+104·6
8.	11 25	46 23	41 11	59	30·05	2800	11·05	2788·95	2516	+272·95
10.	2 31	48 12 30	33 12	58·5	29·95	2400	11·6	2388·4	2320	+ 68·4
11.	1 4	48 49	28 55	58	30·05	1920	12·85	1907·15	1861	+ 46·15
11.	6 46	48 56	28 3	57	30·0	1630	14·5	1615·5	1700	− 84·5
24.	1 0	Victoria Docks.	......	57	30·05	11	16·05	5·05		

care peculiar to the observer; but no such cause could possibly have operated regarding the observations of the instrument recorded in the series of observations given in the second Table, when the vessel passed through seas which had not been before sounded, but which were sounded after each observation of the instrument had been made.

In this Table columns 1 and 2 contain the dates and hours observations were made;
3 and 4, the latitude and longitude of the locality when ascertained;
5, the indications of the thermometer;
6, the indications of the barometer;
7, the indications of the bathometer;
8, the corrections for variations in temperature and atmospheric density;
9, the readings of the bathometer so corrected.
10, the soundings taken.
11, the difference of these and the bathometer indications.

The soundings were made by means of Sir WILLIAM THOMSON'S steel-wire sounding-apparatus, by which admirable improvement over the old sounding-line it is now possible to take soundings exceeding 2000 fathoms in an hour, when 5 or 6 hours were formerly required, and by the application of mechanical power to recover the steel wire itself in from 15 to 20 minutes when a detaching-weight is employed.

The reading of the bathometer was in each case reported to Captain TROT, of the steam-ship 'Faraday,' before the sounding-line had reached the bottom; and the fair accordance between the results obtained by sounding and those given by the instrument furnishes ample proof of the reliable nature of the bathometer indications. The series of observations was unfortunately interrupted during the homeward voyage by a heavy gale, whereby the instrument was exposed to splashes of sea-water from the deck; it had to be taken down, and was only remounted when the vessel had arrived at Victoria Docks. It will be observed that the readings taken in the Victoria Docks, before and after the voyage, agree, after allowing for difference of temperature and atmospheric density, within 5 divisions on the scale of the instrument, representing 5 fathoms of depth, an accordance which must be considered highly satisfactory.

Influence of Elevation above the Earth's surface.—The bathometer is applicable also to the measurement of height, for which purpose it possesses the advantage over the aneroid barometer that its indications are not affected by changes of atmospheric pressure, excepting the small correction for change of atmospheric density before referred to, and which could be avoided in excluding the atmosphere from the extremities of the mercury column.

The total attraction of the earth varies in the inverse ratio of the square of the distance from the centre of the earth; and the ratio of the attraction on the surface of the earth, and at a height h above the surface (supposing the earth to be a sphere), will be expressed by

$$\frac{w}{w'}=\frac{(\mathrm{R}+h)^2}{\mathrm{R}^2},$$

which for relatively small values of h may be written

$$\frac{w}{w'}=\frac{R+2h}{R}$$

or

$$\frac{w-w'}{w}=\frac{h}{\frac{1}{2}R},$$

proving that attraction decreases with elevation in the simple ratio of $\frac{1}{2}$R. The decrease on account of depth of sea takes place, as shown on page 674, nearly in the ratio of R, or the readings of fathoms on the bathometer may be taken for yards in raising the instrument above the sea-level.

The corrections for latitude necessary for reading depth of sea are also applicable for height; but in the latter case another correction will have to be made for the attractive force exercised by the mass composing the mountain or elevation above the sea-level supporting the instrument, and this will vary greatly with the breadth, being a maximum in the case of an elevated plateau. The instrument will, in such cases, give indications of height considerably below the real elevation, and it is doubtful on that account whether it can be made available for such a purpose.

Test for Elevation.—Being desirous to test the instrument for height, I decided to take it up a tower; and having obtained the permission of the Board of Works, through my friend Dr. PERCY, to make use of the Clock Tower for the purpose, the instrument was tested on the 18th of December, the readings being as below:—

	Bathometer. (Mean*.)	Thermometer.	Barometer.
At top of tower . . .	1067·75	45°·0	29·64
At foot of tower . .	1022·5	45·63	29·88

being a difference of 45·25 divisions, equivalent to a difference of height of 135 feet, the aneroid indicating a difference of 208 feet. This difference of readings may appear at first sight excessive, but may be accounted for by disturbance of the instrument in taking it by hand up the steep steps of the tower, where little time was allowed to insure the complete readjustment of the column. In this case also the reading of the instrument gives a result inferior to the indications of theory as compared with its indications on board ship, which latter indications I consider are the more reliable, because the instrument, when once suspended, is not disturbed, and its indications are rendered more delicate through the oscillations of the vessel.

Modifications in the Instrument.—The instrument, as constructed at present, leaves room for such improvements as have partly been, and are likely still, to be suggested by experience. It would be possible to eliminate entirely the effect of variation of temperature by more carefully proportioning the diameter of the mercury column to that of the cup. The influence of variation of density of the atmosphere might also be entirely eliminated if the spaces in the cups above and below the mercury column were closed against the atmosphere, and were brought into communication with each other. The mode of reading the instrument may also be simplified in various manners, or the instrument may be made self-recording by the addition of a chronograph. My present object has been to demonstrate the possibility of constructing a bathometer capable of giving indications of moderate variations in the depth of sea below a vessel, and to describe rather the instrument actually used than such modifications as may prove more advantageous hereafter.

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* Including correction for variation in atmospheric density.

Practical uses of Bathometer.—The useful purposes for which a bathometer, so arranged as to be observable without difficulty by the commander of a ship, may be employed, are, I think, apparent. It often happens at sea that through clouded skies and fogs it is impossible for astronomical observations to be taken, and it is well known that the compass and dead-reckoning are very uncertain guides to the position of a ship; and as the sounding-line can only be of assistance after the ship has arrived at such depths as are positively dangerous, many calamities are on record where, under such circumstances, not only sailing-vessels, but well-equipped steamers have run ashore. The indications of the bathometer would warn the commander of a vessel of the gradual approach of shallow water; and if in possession of accurate charts, he would in many cases be able to determine his actual position by noting in which direction and at what rate the depth varies.

Position obtained by Soundings.—An illustration from actual practice may serve to show how accurate a guide a knowledge of the depth of the sea can be made. In laying the Direct United-States Cable to America, of which operation Mr. CARL SIEMENS took the principal charge, it occurred that, in November 1874, heavy weather had prevented the taking of observations for three days, when an increasing gale, and the suspicion of a slight fault having passed overboard, rendered it necessary to cut the cable and buoy the end. Before cutting the cable a sounding was taken by Sir WILLIAM THOMSON's wire, and the depth was found to be 800 fathoms. The gale lasted several days; and when the 'Faraday' returned to the spot where the end was supposed to be buoyed, no buoy could be found, and it became evident that it had been torn away from the anchor-chain by the violence of the gale. The sounding taken at the point where dead-reckoning had placed the ship at the time of buoying the cable gave a depth of 521 fathoms, lat. 48° 32′ N., long. 45° 21′ W., and showed at once that the end of the cable must be looked for elsewhere. There exists no chart of the part of the Atlantic in question, giving such soundings as might have assisted in the search; but special soundings were taken in all directions, from which the dip of the Atlantic basin in that locality could be ascertained. The cable was parted over a depth of 800 fathoms; and in constructing the contour-lines of the Atlantic basin in the locality, which was dipping towards the N.E., it became evident that in order to obtain the cable with the grapnel, it must be caught up in a line parallel to the contour-line, but a mile or two to the eastward. The expedient adopted proved successful, and the cable was recovered in lat. 48° 44′ N., long. 44° 44′ W., or at a point 25 nautical miles removed from the place where it was supposed to have been lost (see Plate 63. fig. 3). If complete information regarding the depth of the Atlantic Ocean had been available in laying the cable, and if the steam-ship 'Faraday' had at that time been furnished with a reliable bathometer, the uncertainty regarding the position of the vessel when the cable was buoyed would never have arisen, and much anxiety and time would have been saved in recovering the end. In cable-laying a bathometer is more particularly of use, because the amount to which the retarding-brake has to be weighted bears a definite relation to the depth of sea traversed; and an accurate knowledge of that depth is essential to prevent either loss of cable from excessive slackness, or permanent danger through an insufficiency.

A bathometer of careful construction would be extremely useful in increasing our knowledge of the depth of the ocean, whilst instruments of inferior accuracy would serve the useful purpose of furnishing the navigator with timely warning of approaching shallows.

It is chiefly with a view to this latter result that I venture to place my inquiries into this subject before the Royal Society. In doing so I wish to acknowledge the valuable assistance I have received from Mr. BAMBER and Dr. HIGGS, the former having conducted the experiments to determine the influence of temperature on the elasticity of springs, and effected the adjustment of the instruments on land, while the observations on board ship were taken by Dr. HIGGS.

ADDENDUM.—*On an Attraction-meter.*

Received February 23, 1876.

At the reading of the foregoing paper, I exhibited an instrument for measuring horizontal attractions, which, at the same time, illustrates the action of the bathometer. This instrument (Plate 65) consists of a horizontal tube of wrought iron 400 millims. long, terminating at each end in a horizontal transverse tube of cast iron of 60 millims. diameter and 300 millims. long. The first-named horizontal tube is partially closed at its ends, and communicates with the transverse tubes below their horizontal mid section. The transverse tubes communicate also by means of a horizontal glass tube of 2 millims. diameter at a superior level to the former.

The whole apparatus being mounted upon three set-screws is filled to the level of the half-diameter of the transverse tubes with mercury, which mercury fills also the whole of the longitudinal connecting-tube; the upper halves of the cast-iron transverse tubes and the glass connecting-tube are filled with alcohol tinted with cochineal, comprising, however, a small bubble of air, which can be made to occupy a central position in the glass tube by raising or lowering the set-screws.

If a weighty object is approached to either extremity of the connecting-tube an attractive influence will be exercised upon the mercury, tending to a rise of level in the reservoir near at hand, at the expense of the more distant reservoir; and this disturbance of level between the two reservoirs must exercise a corresponding effect upon the index of air in the horizontal glass tube, moving it away from the source of attraction. The amount of this movement must be proportionate to the attractive force thus exercised, and is considerable, because the transverse cross section of each reservoir-tube is $60 \times 300 = 18{,}000$ square millims., whereas the section of the glass tube is only about 3 millims.; the motion produced by the effect of gravity is thus increased 3000-fold, and could easily be increased, say 30,000-fold, by simply increasing the horizontal area of the transverse or reservoir-tubes. Variations of temperature have no effect upon this instrument, because the liquids contained on either side of the index of air are precisely the same in amount; and the total expansion of the liquids is compensated for by an open stand-tube rising up from the centre of the connecting-tube, through which the apparatus can be easily filled. By means of this instrument the effect of 1 cwt. approached to one end or the other of the mercury connecting-tube causes a sensible motion of the air index.

It is suggested that an instrument of this description may be employed usefully for measuring and recording the attractive influences of the sun and moon which give rise to the tides. The instrument, which is of simple construction and not liable to derangement from any cause, would have to be placed upon a solid foundation with its connecting-tube pointing east and west, records being taken either by noting the position of the index upon the graduated scale below, or by means of a self-recording arrangement through photography.

This mode of multiplying the effect produced by gravitation is applicable also to the bathometer; and one of these instruments was shown which was fitted with a spiral glass tube laid horizontally upon the upper surface of the bathometer upon a regularly divided scale, which horizontal tube is connected at one end with the uppermost chamber of the bathometer above the mercury, while the other end remains open to the atmosphere. The space above the mercury in the upper chamber is filled by preference with oil, which terminates in the horizontal spiral glass tube at a point which will vary with the total attractive influence of the earth, and thus furnish a means of reading the instrument. The electric contact arrangement described in the paper is thus rendered unnecessary, and the reading of the instrument much simplified.

Received December 19, 1876.

Since presenting my Paper on the Bathometer to the Royal Society in February last, I have continued my endeavours to produce an instrument in such a form as to be practically independent of the disturbing influences to which reference is made in my paper, and of a construction so simplified as to render the instrument available for practical uses.

It is my intention to present before long a supplementary paper to the Royal Society describing the improved instrument, and giving an account of the further trials which I have had the opportunity of making, for the purpose of verifying the indications of the instrument by actual sounding.

The first set of observations was made by Mr. Alexander Siemens, on board the steam-ship 'Faraday,' in American waters of a depth not exceeding 100 fathoms, when the readings were found to accord closely with the results of sounding. Besides this, several trials of the instrument have been made: one under my immediate superintendence in crossing lately from New York to Liverpool, on board the steam-ship 'Bothnia,' Capt. M'Mickan (who rendered me every facility); another on board H.M. steam-ship 'Fawn,' between Southampton and Gibraltar; while another has been made, at the instance of Dr. Higgs, with a modified form of apparatus, on board a sailing-ship in its passage from Southampton to Rio Janeiro. The results of the observations on board the 'Fawn' were unsatisfactory, owing to a mechanical defect in the apparatus, whereas the others confirmed generally the results given in my paper, confirming also the observation there referred to, that differences of latitude do not seem to exercise the full amount of effect upon the instrument which might be expected, in consequence of the combined influence of centrifugal force and ellipticity of the earth.

Criticisms have appeared in several papers questioning the applicability of the bathometer for determining the depth of the sea, owing to the disturbance of the sea-level by continental attraction. This cause of disturbance had not escaped my attention in writing my paper*; and it should be borne in mind that the instrument cannot do more than indicate comparatively small variations in total terrestrial attraction, which the hydrographer or navigator using the bathometer will have to interpret according to the circumstances of the case. The zero-point of the instrument must vary no doubt with latitude, continental attraction, and also in consequence of special geological causes; but it is important to observe that these causes are of a permanent character, and that if an ocean has been once surveyed with the aid of the bathometer, such special local conditions would become observed facts, and so far from hindering the advantageous use of the instrument, would serve, on the contrary, to increase its measure of usefulness in the hands of the navigator.

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* See page 682.

In the Addendum to my paper of the 23rd February, I described a modification of the principle of the bathometer, designed for the purpose of measuring horizontal attraction; and I take this opportunity of stating that I have constructed an instrument of this description, which has been erected upon a solid foundation at the Loan Exhibition, South Kensington. The measure of sensitiveness of this instrument is given by the fact, that the weight of a person stepping from one side of it to the other causes the indicating bubble to travel through one division (of 1 millim.) of the scale. It would not be difficult to construct such an instrument of still greater sensitiveness; and I believe that it could be made a useful adjunct at physical observatories, for the observation of diurnal changes in the horizontal attraction produced by the sun and moon as well as of terrestrial causes of disturbance of the superficial equilibrium of the earth.

XXVI. *Electrodynamic Qualities of Metals* (continued from Phil. Trans. Vol. 146. Read Feb. 28, 1856).—Part VI. *Effects of Stress on Magnetization.* *By* Sir WILLIAM THOMSON, *F.R.S. &c.*

Received and Read May 27, 1875.

178. In Parts III. and IV. of my first series of papers under this title (Transactions of the Royal Society for February 1856), I described experiments discovering effects of stress on the thermo-electric quality and the electric resistances of metals. About the time those experiments were made I also made several nugatory attempts to discover the effects of stress on magnetization; and eighteen years have passed before I have been able to resume the investigation. Early in the year 1874 I made arrangements to experiment on the magnetization of iron and steel wires in two different ways—one by observing the deflections of a suspended magnetic needle produced by the magnetization to be tested, the other by observing the throw of a galvanometer-needle, due to the momentary current induced by each sudden change of magnetism. The second method, which for brevity I shall call the ballistic method, was invented by WEBER, and has been used with excellent effect by THALÉN, ROLAND, and others. It has great advantages in respect of convenience, and the ease with which accurate results may be obtained by it; but it is not adapted to show slow changes of magnetism, and is therefore not fit for certain important parts of the investigation. On this account I am continuing arrangements for carrying out the first method, although hitherto I have obtained no good results by it.

179. On the other hand, I have found the ballistic method very easy and perfectly satisfactory in every respect, except that it does not show the slow changes of magnetization. It was by it that all the results which I am now going to describe were obtained. The apparatus, which is very simple, is represented in the accompanying sketch (fig. 1).

A A′ is the wire whose magnetism is experimented on. In my first experiments it was a piece of steel pianoforte-wire, No. 22 *, Birmingham wire-gauge, that is, weighing about 3·54 grammes per metre, and therefore of ·7644 of a millimetre in diameter. It is about 5 metres long, and its upper end is firmly fixed to a beam in the ceiling of the Physical Laboratory of the University of Glasgow, where all the experiments have been made. To the lower end is attached a pan bearing weights, by means of which different amounts of pull may be rapidly applied and removed from the wire when desired. Over a portion C C′ of this wire 28·7 centimetres long there is wrapped a piece of thin sheet copper, and on the outside of that there is coiled, in two layers, 719·7 centimetres of silk-covered copper wire, the copper weighing 2·502 grammes per metre. The inner layer contains 326 turns and the outer 321. The resistance of this coil when cool is ·511 ohm. Its ends are put in communication by thick electrodes with a reversing-key, *k*, and a battery of three of my "tray" Daniells. The resistance of each of these cells is about ·06 of an ohm, giving for the whole battery a resistance of ·18 ohm.

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* This is the wire used in the American Navy and in British cable-ships for deep-sea soundings. Its strength to resist pull is such that it bears about 230 lbs. (104 kilogrammes), or the weight in air of 29·4 kilometres (or 15·9 nautical miles) of its own length.

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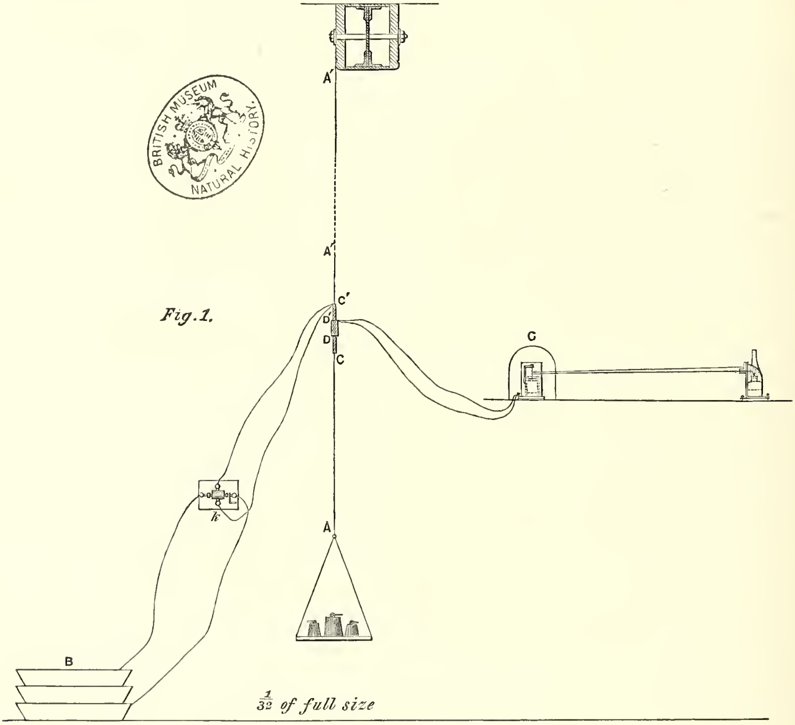
Fig. 1.



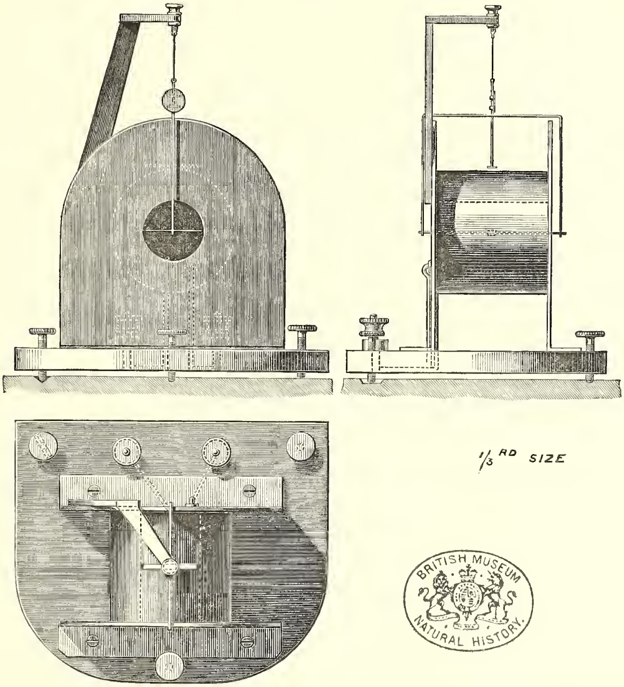
$\frac{1}{32}$ *of full size*

180. Over the coil C C′ is wound another coil D D′ 9·8 centimetres long, which contains 538 centimetres of wire, No. 26 of the Birmingham wire-gauge, with 38 centimetres for electrodes. This wire is also wound on in two layers, the inner containing 147 turns and the outer 146. The resistance of this induction-coil is 1·432 ohm, and its weight per metre 1·189 gramme.

181. The deflections of the galvanometer are read in my usual manner by the image of a fine wire fixed vertically close in front of the edge of a flat paraffine- or gas-flame. The screen on which the image is thrown is a white paper scale, divided into fortieths of an

inch, fixed at a distance of 49·8 inches from the mirror. The lamp is placed close behind the middle of the scale, and just enough below to allow its light to pass under the scale to the mirror through a small blackened tube. The galvanometer used is represented in the accompanying sketch (fig. 2). Having been extemporized from a large lecture-room instrument, it is not so well adapted for this investigation as I could wish. It consists of an astatic pair of needles mounted on a light frame of aluminium, and carrying a light mirror placed on the frame, with its centre in the line of the suspension a little above the upper needle, and attached by means of clips, so as to admit of its being turned into and fixed in any position relatively to the frame. The resistance of the galvanometer-coil is ·634 ohm.

Fig. 2.



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182. On commencing to experiment with this apparatus in March 1874, I immediately obtained some very startling and interesting results. I found that when a current was kept flowing through the magnetizing coil, and weights were alternately placed on the pan at the lower end of the wire and taken off, the effect of the pull

always diminished the magnetization, and the effect of removing the pull increased it*. The magnetizing current being then stopped, and the same operation with the weights repeated, I found similar effects—that is, the application of a pull diminished the residual magnetization, and the removal of the pull increased it. But, to my surprise, the effect was greater in this second case when merely residual magnetism was concerned than in the first case when the original magnetizing force was still in action. This greater effect in the second case was surprising, because the whole magnetization concerned in the first case was greater than the magnetization concerned in the second case by the amount of the quasi-elastic magnetization, which goes and comes again every time the magnetizing force is removed and reapplied.

183. The amount of the magnetizing force used may be roughly estimated by taking the electromotive force of each of the three cells as one volt, or 10^8 centimetre-gramme-second units. Thus, as the resistance in the circuit was about ·69 of an ohm, the strength of the current must have been about $\frac{3\times10^8}{\cdot69\times10^9}$ or $\frac{1}{2\cdot3}$. This was distributed in 647 turns of a solenoid whose axis was 28·7 centimetres long. The whole strength of current circulating round a length δx of the solenoid was therefore $\frac{647}{28\cdot7}\times\frac{1}{2\cdot3}\delta x$, and the magnetizing force to which the steel wire was subjected $4\pi\frac{647}{28\cdot7}\times\frac{1}{2\cdot3}$, or 123. Hence, as remarked by Professor MAXWELL, who, in reporting on this paper, first made the preceding estimate, we may call the magnetizing force a large one, so large, in fact, that it probably magnetizes the wire nearly to saturation at once. For the sake of comparison it may be remarked that the horizontal and vertical components of the earth's magnetic force at Glasgow are about ·16 and ·43; and in first experimenting with the apparatus now described, I made sure that the magnetization of the wire by the vertical component of the earth's magnetizing force was not essentially concerned in any of the results, by reversing the magnetizing current, then applying and removing weights repeatedly, then stopping the current, and again putting weights on and off repeatedly. The deflections of the galvanometer observed in this succession of operations were not sensibly different from those observed previously, but in reverse directions; that is to say, the results still fulfilled the preceding statements.

The fact that the effect of pull to diminish magnetization and of taking off pull to increase it, was found to produce a greater difference when the magnetization was solely residual than when it was sustained by the continued influence of the magnetizing force, led me to expect that the effect of making and breaking the circuit of the magnetizing coil and battery should be greater for the wire when pulled than when unpulled. Subsequent experiments proved this to be the case.

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* Since the communication of this paper to the Royal Society I have found in WIEDEMANN's 'Galvanismus,' § 499, that similar results had been obtained by MATTEUCCI ('Annales de Chimie et de Physique,' 1858), and by VILLARI (POGG. 'Annalen,' 1868).—[Added May 1876.]

184. But, lastly, I found between the quasi-elastic part of the magnetization produced by alternately applying and removing the magnetizing force, and the initial reverse magnetization produced by the application of a reverse magnetizing force, a very surprising difference. The former, as stated above, is greater when the wire is pulled than when unpulled: the latter is less in the wire when pulled than when free from pull, but not by so great a difference; and the whole magnetizational effect of reversing the current suddenly must therefore be greater when the wire is pulled than when unpulled, and is found to be so.

185. The following series of experiments, I. . . . . XXXI., performed in November and December 1874, all on one and the same piece of steel wire, first confirmed the conclusions inferred (§ 182) from the preliminary investigation of the previous March, then reproduced with more regularity the immediate experimental results of that preliminary investigation, and lastly discovered the very remarkable phenomena described in § 184.

186. The general order of procedure followed was this. The image on the scale of the ballistic galvanometer was watched by one observer, while a second stood by to make or break circuit of magnetizing current, or put on and off weights, on word of command from the first. When the image is seen to be steady on the scale, the number at which it stands is read and recorded as "z" (zero). The order "make" or "break" or "on" or "off" is given by the first observer and executed suddenly by the second. The first observer reads and records the greatest or least number on the scale reached by the image in consequence of the electromagnetic impulse produced by the operation. Finally, the excess (positive or negative) of this reading above the immediately preceding zero is written down and marked "M" or "B," or "On" or "Off," as the case may be.

187. The connexions chanced to be so arranged that, with the direction of current invariably used in the "M's" of Series I. . . . . XXIX., the effect of M was to throw the image to the left, or in the direction of decreasing numbers: thus until Series XXX. a negative number always shows increase of magnetization in the direction of that produced by M. The numbers actually written down by the observers during the experiments are shown in the following extracts from their day-book, for a few of the series, chosen as examples to precede the abridged Tables of results given below for all the Series I. . . . . XXX.

December 2, 1874.

	VIII. 112 lbs. On.		IX. 112 lbs. Off.	
Z	376		362	
M	328	−48	339	−23
Z	373		359	
B	413	+40	380	+21
Z	374		360	
M	332	−42	335	−25
Z	373		358	
B	413	+40	381	+23
Z	375		358	
M	333	−42	336	−22
Z	371		358	
B	410	+39	379	+21
Z	372		358	
M	330	−42	333	−25
Z	373		357	
B	412	+39	380	+23
Z	376		359	
M	335	−41	335	−24
Z	374		357	
B	413	+39	380	+23
Z	377		360	
M	335	−42	335	−25
Z	377		357	
B	415	+38	378	+21
Z	377		354	
M	335	−42	330	−24
Z	375		353	
B	414	+39	376	+23
Z	378		355	
M	335	−43	331	−24
Z	377		353	
B	416	+39	376	+23
Z	374		354	
M	332	−42	330	−24
Z	372		353	
B	411	+39	375	+22
Z	374		356	
M	333	−41	331	−25
Z	369		355	
B	407	+38	376	+21

December 7, 1874.

112 lbs. On and Off.

XVI. No current*.			XVII. Current flowing.	
Z	362		357	
On	404	+42	377	+20
Z	365		354	
Off	342	−23	335	−19
Z	360		352	
On	386·5	+26·5	372	+20
Z	360		352	
Off	336·5	−23·5	334	−18
Z	365		353	
On	393	+28	374	+21
Z	364		353	
Off	339	−25	335·5	−17·5
Z	362		362	
On	388	+26	380·5	+18·5
Z	365		353	
Off	340·5	−24·5	334·5	−18·5
Z	367		353	
On	391	+24	372·5	+19·5
Z	367		350	
Off	345	−22	331·5	−18·5
Z	367		357	
On	390·5	+23·5	376·5	+19·5
Z	369		360	
Off	347·5	−21·5	341	−19
Z	369		359	
On	394	+25	379	+20
Z	369		357	
Off	346	−23	331·5	−25·5
Z	370		354	
On	393	+23	373	+19
Z	370		353	
Off	347·5	−22·5	333	−20
Z	370		349	
On	392	+22	368	+19
Z	368		346	
Off	345·5	−22·5	326	−20
Z	365		346	
On	392	+27	366	+20
Z	364		342	
Off	341·5	−22·5	322	−20

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* The effects here observed were diminutions and augmentations of residual magnetism from previous operations.

188. Each series from I. to XXIX. was conducted with perfect regularity on one or other of several plans, of which the details are sufficiently exemplified in the preceding unabridged quotations. Omitting now the actual readings and taking merely the differences from the zeros, we have the following full statement of results showing the amount of the electromagnetic impulse produced by each operation.

[Addition, May 1876.—It must not be assumed that the apparent accumulations of magnetization shown in the last columns of the Tables I. . . . . IX., or that the differences of demagnetizations and magnetizations shown at the foot of each of the Tables down to XVII., express correctly the whole changes of magnetization of the wire; for, as remarked above (§ 178), the ballistic method does not show slow changes of magnetization; and there certainly were slow changes of magnetization not shown in my ballistic experiments; because the algebraic sum of all the deflections observed day after day went on sometimes continually increasing and sometimes continually diminishing, when it was certain that there was no corresponding progressive accumulation of magnetization or of demagnetization. Some of the experiments by the method of deflection promised in § 178 were performed in last July and August, soon after the communication of this paper, and gave very remarkable results, which were free from the objection of dropping out of account slow changes of magnetization. They include effects of torsion as well as of pull. I intend to include a statement of them in a paper which I hope soon to be able to offer to the Royal Society.]

Series I. to IX.—Magnetizing Current made and broken.

November 26, 1875.—I. Weights off.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
26	23	3	3
24	21	3	6
25	23	2	8
24	21	3	11
24	21	3	14
23	21	2	16
24	22	2	18
24	21	3	21
24	21	3	24
23	22	1	25

Series I.–IX. (continued).

November 26, 1875.—II. 28 lbs. on.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
26	22	4	4
24	22	2	6
24	26	−2	4
24	22	2	6
25	22	3	9
26	23	3	12
24	22	2	14
25	22	3	17
25	23	2	19
24	20	4	23

November 27, 1875.—III. Weights off.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
24	21	3	3
24	22	2	5
24	21	3	8
24	21	3	11
22	20	2	13
24	22	2	15
24	21	3	18
23	21	2	20
24	20	4	24
23	20	3	27

November 30, 1875.—IV. 56 lbs. on.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
30	26	4	4
29	27	2	6
28	26	2	8
28	26	2	10
28	24	4	14
28	25	3	17
28	25	3	20
29	26	3	23
27	25	2	25
28	26	2	27

Series I.–IX. (continued).

November 30, 1875.—V. Weights off.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
23	21	2	2
24	22	2	4
23	22	1	5
24	22	2	7
24	22	2	9
23	20	3	12
23	21	2	14
24	21	3	17
24	21	3	20
24	21	3	23

December 1st, 1875.—VI. 84 lbs. on.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
35	33	2	2
33	31	2	4
33	30	3	7
36	32	4	11
33	31	2	13
35	32	3	16
35	33	2	18
34	31	3	21
35	31	4	25
35	31	4	29

December 1, 1875.—VII. Weights off.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
26	23	3	3
26	23	3	6
25	22	3	9
26	23	3	12
26	23	3	15
26	23	3	18
25	24	1	19
26	23	3	22
26	23	3	25
26	24	2	27
25	24	1	28

Series I.–IX. (continued).

December 2, 1875.—VIII. 112 lbs. on.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
48	40	8	8
42	40	2	10
42	39	3	13
42	39	3	16
41	39	2	18
42	38	4	22
42	39	3	25
43	39	4	29
42	39	3	32
41	38	3	35

December 2, 1875.—IX. 112 lbs. on.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
−23	+21	−2	2
−25	+23	−2	4
−22	+21	−1	5
−25	+23	−2	7
−24	+23	−1	8
−25	+21	−4	12
−24	+23	−1	13
−24	+23	−1	14
−24	+22	−2	16
−25	+21	−4	20

Series X.–XVII.—Weights on and off.

	28 lbs.		56 lbs.	
	X. December 3. No current.	XI. December 3. Current flowing.	XII. December 4. No current.	XIII. December 5. Current flowing.
On	+5·5	+3·5	+15	+10
Off	−5	−4	−10·5	−10
On	+5	+4	+11·5	+ 9
Off	−4·5	−5	−12	− 9
On	+5·5	+5	+11	+10
Off	−5	−3·5	−11·5	− 8
On	+5	+4	+ 9·5	+ 9·5
Off	−5	−4·5	−11	− 8
On	+5	+5	+11	+ 9
Off	−5	−3·5	−10·5	− 7
On	+5·5	+3·5	+12	+10
Off	−5	−5	−10	− 7
On	+5	+3·5	+10·5	+10
Off	−4	−5·5	−10	− 9
On	+5	+4	+10	+10
Off	−5	−3·5	−10·5	− 9
On	+4·5	+4	+13·5	+ 9
Off	−4·5	−5	−10	− 9·5
On	+5	+3·5	+12	+10·5
Off	−5·5	−4·5	−11	− 9

Means of the ten 'ons' and ten 'offs.'

	Ons.	Offs.	Ons.	Offs.	Ons.	Offs.	Ons.	Offs.
	5·10 demagnetization.	4·85 magnetization.	4 demagnetization.	4·4 magnetization.	11·6 demagnetization.	10·7 magnetization.	9·7 demagnetization.	8·55 magnetization.
	Excess of demagnetizations above magnetizations.		Excess of magnetizations above demagnetizations.		Excess of demagnetizations above magnetizations.		Excess of demagnetizations above magnetizations.	
	2·5		4		9		11·5	

Series X.–XVII.—Weights on and off (continued).

	84 lbs.		112 lbs.	
	XIV. December 5. No current.	XV. December 7. Current flowing.	XVI. December 7. No current.	XVII. December 7. Current flowing.
On …………	+28	+16	+42	+20
Off …………	−16	−15·5	−23	−19
On …………	+18	+13·5	+26·5	+20
Off …………	−16	−14·5	−23·5	−18
On …………	+18	+15·5	+28	+21
Off …………	−16·5	−13	−25	−17·5
On …………	+18	+14	+26	+18·5
Off …………	−18	−14	−24·5	−18·5
On …………	+18	+13·5	+24	+18·5
Off …………	−19	−15	−22	−18·5
On …………	+17·5	+17	+23·5	+19·5
Off …………	−18·5	−13·5	−21·5	−19
On …………	+18·5	+16	+25	+20
Off …………	−17	−14·5	−23	−25·5
On …………	+16·5	+17·5	+23	+19
Off …………	−18·5	−15·5	−22·5	−20
On …………	+18	+16	+22	+19
Off …………	−17·5	−14·5	−22·5	−20
On …………	+19	+14·5	+27	+20
Off …………	−16	−15·5	−22·5	−20

Means of the ten 'ons' and ten 'offs.'

Ons.	Offs.	Ons.	Offs.	Ons.	Offs.	Ons.	Offs.
18·95 demagnetization.	17·3 magnetization.	15·35 demagnetization.	14·55 magnetization.	26·7 demagnetization.	23 magnetization.	19·55 demagnetization.	19·6 magnetization.
Excess of demagnetizations above magnetizations.		Excess of demagnetizations above magnetizations.		Excess of demagnetizations above magnetizations.		Excess of magnetizations above demagnetizations.	
16·5		8		37		5	

Series XVIII., XIX., XX.—Cycles M, On, B, Off.

	XVIII. December 8.	XIX. December 8.	XX. December 9.
	56 lbs.	84 lbs.	112 lbs.
M	−28	−27	−41
On	+ 6	+12	+20
B	+26	+31	+38
Off	− 7	−15	−21
M	−33	−36	−40·5
On	+ 9·5	+13	+18·5
B	+25	+29·5	+38·5
Off	− 7	−14	−22
M	−30	−34	−42·5
On	+ 7·5	+14·5	+18
B	+27	+32·5	+38·5
Off	− 8	−14	−22·5
M	−34	−35·5	−45
On	+ 9·5	+13·5	+19
B	+22	+29	+39·5
Off	− 8·5	−16	−21·5
M	−31	−36	−42·5
On	+10·5	+13·5	+20
B	+28	+30·5	+38·5
Off	− 8	−15	−21

Series XXI., XXII., XXIII.—Cycles On, M, Off, B.

	XXI. December 9.	XXII. December 9.	XXIII. December 10.
	56 lbs.	84 lbs.	112 lbs.
On	+15·5	+26	+37
M	−31	−39	−43
Off	− 9	−15	−22
B	+23	+24	+23·5
On	+16·5	+25·5	+37
M	−29·5	−39	−41
Off	−10	−16	−22
B	+22	+24	+24
On	+15·5	+26	+37·5
M	−31	−38	−42
Off	−10	−16	−21
B	+22	+24	+24
On	+15	+27	+36
M	−29	−39	−41
Off	−10	−16	−20·5
B	+21·5	+24	+23·5
On	+15·5	+26	+38
M	−28·5	−38	−42
Off	−10	−16	−21
B	+22	+25	+24

Series XXIV., XXV., XXVI.—Cycles M, On, Off, B.

	XXIV. December 10.	XXV. December 10.	XXVI. December 10.
	56 lbs.	84 lbs.	112 lbs.
M	−27	−25	−26
On	+10	+15	+20
Off	− 9·5	−14·5	−19·5
B	+22	+24	+24
M	−26	−24	−25·5
On	+10·5	+14	+20
Off	− 9	−14·5	−19
B	+21	+22	+22
M	−26	−24	−26
On	+ 9·5	+15	+20
Off	−10	−15	−20
B	+22	+23	+21
M	−25	−26	−24
On	+ 9	+15	+20
Off	− 9	−14·5	−22
B	+23	+24	+24
M	−25	−26	−25·5
On	+ 8	+14	+21
Off	− 9	−14·5	−23
B	+23	+24	+25

Series XXVII., XXVIII., XXIX.

Cycles (again the same as those of XVIII., XIX., XX.) M, On, B, Off.

	XXVII. December 14.	XXVIII. December 15.	XXIX. December 16.
	56 lbs.	84 lbs.	112 lbs.
M	−30	−30	−31
On	+ 9·5	+14·5	+18·5
B	+28·5	+34	+40
Off	− 8	−14·5	−21·5
M	−33	−39	−44
On	+ 8·5	+13·5	+18·5
B	+29	+34·5	+40
Off	− 7	−15	−22
M	−34	−37·5	−42
On	+ 8·5	+16	+18
B	+29·5	+34·5	+40
Off	− 8	−14	−20
M	−34	−38	−43
On	+ 9	+14	+20
B	+28	+35	+39·5
Off	− 6·5	−14·5	−23
M	−34	−37	−42
On	+ 9	+12·5	+20
B	+28	+34	+38
Off	− 7	−14	−19

189. Series XXX. and XXXI. were irregular. After putting on and off weights several times, and finding as before diminutions and augmentations of residual magnetism, a weight of 28 lbs. was left on the wire, and the magnetizing circuit was made with current in the same direction as before; then an additional 28 lbs. on and off: the current once more made and broken, still in same direction; then circuit made in reverse direction, and broken; lastly, 28 lbs. additional put on and taken off. The results were as follows, M(−) being now used to denote institution of current in one final direction, and M(+) in the opposite direction.

Latter part of Series XXX. December 22, 1875.—28 lbs. permanently hung on wire. "On" and "off" means another weight of 28 lbs. put on and taken off.

On	+ 5·5
Off	− 4·5
M(−)	− 42
On	+ 5·5
Off	− 6
B	+ 24·5
M(−)	− 28
B	+ 26
M(+)	+181
B	−25
On	−10
Off	+ 5·5
On	− 6
Off	+ 6
On	− 7
Off	+ 6·5
On	− 6
Off	+ 5
On	− 6
Off	+ 6·5
On	− 6
Off	+ 6
M(−)	−180
On	+ 5
Off	− 6·5
On	+ 5
Off	− 4·5
On	+ 4·5
Off	− 7
On	+ 5
Off	− 5
On	+ 4·5
Off	− 5
B	+26

Series XXXI. December 22, 1875.—Weight of 28 lbs. hung permanently on the wire. "On" and "off" means a weight of 56 lbs. hung on in addition and taken off.

On	+20
Off	−12
On	+13½
Off	−12
M(−)	−40
On	+ 9¼
Off	−10
B	+25½
M(−)	−29
Then immediately, without waiting for image coming to rest,	
B	
On	+19
Off	−12
On	+12
M(−)	−40
B	+36
M(−)	−35½
Off	− 10
On	+ 11½
Off	− 9½
B	+ 23½
M(+)	+180
B	− 24
M(−)	−181
On	+ 9
B	+ 35
M(+)	+150
B	− 35
M(−)	−150
Off	− 11
B	+ 25
M(+)	+182
On and M(−) and B many times quickly.	
M(−)	−34
B immediately after.	
M(+)	+155
Off, and B and M(+) and B many times quickly.	
M(−)	−185
M(−) and B many times quickly.	
M(+)	+184
On. Then M(+) and B many times quickly.	
M(−)	155
M(+) reading lost.	
M(−)	−180
M(+)	+179½
Then immediately, without waiting for image coming to rest,	
Off	
M(−)	−199
M(+)	+198
Then immediately	
On	
M(−)	−181
M(+)	+176
Then immediately	
Off	
M(−)	−199
M(+)	+200
M(−)	−200
M(+)	+200
Then immediately	
On	
M(−)	−180
M(+)	+179
M(−)	−179
Steel wire removed from core, to test the direct induction from coil to coil.	
M(+)	+20
B	−19½

190. Interpretation of Series XXX. with help from Series XXXI.—From each M(∓) and following B subtract and add respectively ∓19¾, or, say ∓20, for induction of coil on coil measured in last two experiments of Series XXXI. Therefore

the first M(−) of Series XXX. gave 22 of increase to the magnetization of the steel wire which had remained for six days undisturbed as left at the end of Series XXIX. After an "on" and "off" of 28 lbs.* the current was stopped, and the magnetism of the wire instantly fell 4·5. A second M(−) gave 8 of increase to the magnetization, while the current was continued, of which 6 was instantly lost when the current was stopped a minute or two after. Then M(+) without other disturbance produced 161 of demagnetization and reverse magnetization, of which 5 was lost when the current was stopped a minute or two after, and 5·5 more in the set of six ons and offs which followed. The residual reverse magnetization must (as we may judge from subsequent results of Series XXX. and XXXI.) have been approximately equal to the immediately previous residual magnetization remaining from all the previous M(−) and other operations to which the wire had been subjected from the time in November when it was set up for the experiments. Subtracting $10\frac{1}{2}$ from 161 we find $150\frac{1}{2}$ for the number measuring the change from the previous (−) magnetization to the equal (+) magnetization in the wire at the present stage of its history. The amount of this magnetization is therefore $75\frac{1}{4}$, say 75. With this amount of magnetization in the wire, and 28 lbs. hanging constantly on it, the effect of putting on and off another 28 lbs. is to diminish and increase the magnetism by 6; that is to say, to diminish it and increase it by about $\frac{1}{12}$ of its mean value (which, according to these rough estimates, is 73 of our arbitrary scale). The remainder of Series XXX. speaks intelligibly for itself.

191. Interpretation of Series XXXI.—The first on gave a diminution 20 in the magnetization, the second $13\frac{1}{2}$; the first on and the off, on, off following, gave on the whole a diminution of $9\frac{1}{2}$, that is to say, shook out $9\frac{1}{2}$ of the 75 of the residual magnetism remaining from Series XXX. The effect of repeated ons and offs on the $65\frac{1}{2}$ of remaining magnetism would no doubt have shaken but very little more out, and would have caused alternate diminutions and augmentations of about 12; that is to say, with 56 lbs. hung on, in addition to the constant 28 lbs., the magnetization of the wire would have been 53, and with only the 28 lbs. it would have been 65.

The M(−), on, off, and B which actually followed, added $15\frac{1}{4}$ to the magnetization, and so brought it up to about $80\frac{3}{4}$, or $5\frac{3}{4}$ more than it had at the beginning of Series XXXI. The subsequent M(−) and B probably produced little, if any, further change in the residual magnetization; and the on, off, on which followed confirmed the previous result of augmentation 12 and diminution 12, alternately by off and on, after something considerable shaken out permanently by the first on. The off, on, off after M(−) with current still flowing gave about 10 instead of the 12 found previously when the current was not flowing. These results agree in kind and amount with what was to be expected from Series XIV. and XV., considering that "on" and "off" in those series was 84 lbs. on and off (with nothing, or only a very slight steadying weight kept always on), whereas now the "on" and "off" means change from 28 lbs. to 84 lbs. and back.

192. Interpretation of Series XXXI. continued.—Taking now the effects of Ms and

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* Another weight of 28 lbs. hanging constantly on the wire.

Bs, and (§ 191) subtracting 20 from each number, we see that the effect on the magnetization of the wire producible by repeating M(—) and B over and over again without other disturbance would be about 16 each way with 84 lbs. on, and probably between $5\frac{1}{2}$ and 9 with 28 lbs. on. (This agrees in kind with the conclusion deducible from the comparison between the previous Series II. and VI.; but the absolute magnitudes of the results seem smaller, probably because of less battery-power in those series than in Series XXXI.) The whole effects of the M(+) after M(—) and B, and of the M(—) after M(+) and B, were still, as in Series XXX., each equal to 180 or 181, with only the 28 lbs. on, and therefore (subtracting 20 for the induction from coil to coil) we had 160 or 161, say $160\frac{1}{2}$, for the sum of the demagnetization and reverse magnetization produced by a M following a B and a previous M of the opposite direction. Now came, in the course of a few minutes, a most startling discovery. With the 84 lbs. on, the sum of magnetization and demagnetization produced by the M after B from previous opposite M was 130, or less by $30\frac{1}{2}$ with those than with the 28 lbs. Thus we see that while the magnetic effect of stopping the current is *greater*, the effect of subsequently instituting the current in the reverse direction is *less*, with the heavy than with the light weight; and less by about three times as great a difference.

193. Consider, lastly, the effect of a sudden reversal of the current. This may be regarded as the sum of the effects of stopping it, and starting it in the reverse direction; and therefore may be expected to be less with the 84 lbs. than with the 28 lbs. by about $\frac{2}{3}$ of the difference between the effects of starting the reverse current with the heavy and with the light weights hung on the wire. This inference is verified in the concluding thirteen results of the series before removal of the steel wire. Thus (§ 190) subtracting 40 for the induction of coil on coil in the reversal, we find 140, $139\frac{1}{2}$, 141, 136, 140, 139, 139 for magnetic effects of reversals with 84 lbs. hung on the wire, of which the mean is 139·2; and 159, 158, 159, 160, 160, 160, for the magnetic effects of reversals with 28 lbs. on, of which the mean is 159·3.

194. After the conclusion of these experiments on the steel wire, I made many experiments of the same kind on soft-iron wires of various qualities substituted for it in the same apparatus, and I have obtained results of the same kind, as to the effects of hanging on and taking off weights, while the magnetizing current is kept flowing. I have also obtained some very remarkable and perplexing results by putting weights on and off with the current not flowing. In one of the iron wires the effect found was opposite to that in steel; that is to say, putting on weight augmented and taking off weight diminished the residual magnetism; in another the same effect as in steel was found, that is, putting on diminished and taking off augmented the residual magnetism. Neither of these was as soft as some of the other wires tried, and the one ("bright soft iron wire," JOHNSTONE's) that agreed with steel was remarked on at the time as *much harder* than another that had been previously experimented on ("black soft iron wire," JOHNSTONE's). This latter seemed utterly destitute of retentive power under the influence of putting the weights on and off. Like all the others it always experienced a diminution

of magnetism by weights on and increase by weights off, when the magnetizing current was flowing. But when the current was stopped large effects (larger than those when the current was flowing) were produced by putting on and taking off the weights; and these effects were always of the same kind, whichever had been the direction of the current.

195. I have not yet been able to explain these effects by terrestrial magnetic force*, nor to even guess any other possible cause; and have in fact, since the 23rd of December last, been exceedingly perplexed by seeming anomalies which the various soft-iron wires tried have presented, commencing that day with a reversal of the electromagnetic effect of the "off" and "on" which the first of the wires experimented on showed after the magnetizing current had been made for the first time and broken, and a weight of 14 lbs. put on and off several times had first shaken out nearly one third of the residual magnetism, and then given alternate augmentation by "on" and diminution by "off" of the magnetism that remained. A weight of 28 lbs. was then hung on, and it stretched the wire permanently by about 8 per cent. of its length. Then immediately I found reverse effects by putting off and on and off the 28 lbs., and on and off smaller weights—the "on" giving diminution and the "off" augmentation of what would have been the residual magnetism, if residual magnetism there was, from the first magnetization by the current. This quality remained until an hour or two later, when the current was once more made in the same direction as the first, and broken again. Then 14 lbs. put on actually gave augmentation of the residual magnetism (instead of shaking out a considerable quantity as the first "on" after the first "B" had done), and the offs, ons, and offs following gave alternate diminution (by the offs) and augmentation (by the ons); that is to say, the effects were the *same in kind* as the effects which had been observed before the stretching by the 28 lbs.; but they were nearly three times as great in amount as they had been then, with the same weight of 14 lbs. on and off. Thenceforth the same piece of wire (experimented on several more days up till Jan. 12, 1875) and other pieces of similar wire tried after it, with the current made sometimes in one direction and sometimes in the other, and broken, and different amounts of weight up to 28 lbs. put on and off, always showed increase of the residual magnetism by the "on" and diminution by the "off." Even the first "on" after the stoppage of the current gave always an increase of the magnetism; but when the weight was as much as 28 lbs. the "shaking out" tendency was remarkably shown by the increase by the first "on" being much less than the diminution by the first "off."

196. The soft-iron wire experimented on on the 23rd of December gave, with 28 lbs. hanging on it, smaller effects of successive "makes," in one direction, and breaks of the current; a greater effect when it was made in the reverse direction; and a smaller sum

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* [Note added January 1877.—Nearly six months later I ascertained that these startlingly great effects actually were due to the vertical component of the earth's force, though this was only about $\frac{1}{300}$ of the magnetizing force of the currents used.]

of these two effects (that is to say, a smaller effect) on the reversal of the current than when it was un-pulled.

197. The investigation is being continued with special arrangements to discover the explanation of the seeming anomalies described above, and with the further object of determining in absolute measure the amounts of all the ascertained effects, at different temperatures up to 100° Cent. It is needless to give in the mean time any minute details of the experiments already made on the soft-iron wires by which the results now described were obtained.

ABSTRACT OF THE PRECEDING PAPER.

WEBER'S method, by aid of electromagnetic induction and a "ballistic galvanometer" to measure it, which has been practised with so much success by THALÉN, ROLAND, and others, has been used in the investigation of which the results are at present communicated; but partial trials have been made by the direct magnetometric method (deflections of a needle), and this method is kept in view for testing slow changes of magnetization which the electromagnetic method fails to detect.

The metals experimented on have been steel pianoforte-wire, of the kind used for deep-sea soundings by the American Navy and British cable-ships; and soft-iron wires of about the same gauge, but of several different qualities.

I. *Steel.*

The steel wire weighs about $14\frac{1}{2}$ lbs. per nautical mile, and bears 230 lbs. Weights of from 28 lbs. to 112 lbs. were hung on it and taken off, and results described shortly as follows were found:—

(1) The magnetization is diminished by hanging on weights, and increased by taking the weights off, when the magnetizing current is kept flowing.

(2) The residual magnetism remaining after the current is stopped is also diminished by hanging on the weights, and increased by taking them off.

(3) The absolute amount of the difference of magnetization produced by putting on or taking off weights is greater with the mere residual magnetism when the current is stopped than with the whole magnetism when the magnetizing current is kept flowing.

(4) The changes of magnetization produced by making the magnetizing current always in one direction and stopping it are greater with the weights on than off.

(5) After the magnetizing current has been made in either direction and stopped, the effect of making it in the reverse direction is less with the weights on than off.

(6) The difference announced in (5) is a much greater difference than that in the opposite direction between the effects of stopping the current with weights on and weights off, announced in (4).

(7) When the current is suddenly reversed, the magnetic effect is less with the weights on than with the weights off.

II. *Soft-Iron Wires.*

Wires of about the same gauge as the steel were used, but, except one of them, bore only about 28 lbs. instead of 230. All of three or four kinds tried agreed with the steel in (1).

The first tried behaved (except a seeming anomaly, hitherto unexplained) in the reverse manner to steel in respect to (2), (4), (5), and (6); it agreed with the steel in respect to (7). Another iron wire*, which, though called "soft," was much less soft than the first, agreed with steel in respect to (1) and (2), but [differing from steel in respect to (3)] showed greater effects of weights on and off when the magnetizing current was flowing than when it was stopped.

Other soft-iron wires which were very soft, softer even than the first, agreed with all the steel and iron wires in respect to (1), but gave results when tested for (2) which proved an exceedingly transient character of the residual magnetism, and were otherwise seemingly anomalous.

The investigation is being continued with special arrangements to find the explanation of these apparent anomalies, and with the further object of ascertaining in absolute measure the amounts of all the proved effects at different temperatures up to 100° Cent.

[Postscript, Jan. 1877.—The proposed continuation of the investigation is still going on. A part of it (of which an abstract, communicated to the Royal Society at its next ordinary meeting after the communication of the preceding paper, has been published in the 'Proceedings' for June 1875) completely explains the "seeming anomalies" of §§ 194, 195, above.]

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* It was tested magnetically with weights up to 56 lbs., and broke, unfairly however, when 63 lbs. were hung on.

XXVII. *On the Nature of the Force producing the Motion of a Body exposed to Rays of Heat and Light.* *By* ARTHUR SCHUSTER, *Ph.D., Demonstrator in the Physical Laboratory of Owens College. Communicated by* BALFOUR STEWART, *F.R.S.*

Received February 24,—Read March 23, 1876.

MR. CROOKES has lately drawn attention to the mechanical action of a source of light on delicately suspended bodies *in vacuo.* I have made a few experiments which will, I think, throw some light on the cause of these phenomena, and assist us in the explanation of the manifold and striking experiments made by Mr. CROOKES.

Whenever we observe a force tending to drive a body in a certain direction we are sure to find a force equal in amount acting in the opposite direction on the body or on the bodies from which the force emanates. It was with the view of finding the seat of this reaction that I have made the experiments described in these pages.

If the force is due directly to radiation, the reaction will be on the radiating body; if, on the other hand, it is due to any interior action, such as the one suggested by Professor REYNOLDS, the reaction will be on the exhausted vessel enclosing the bodies on which the force acts. I have been able to test this by experiment, and have found that the action and reaction are entirely between the light bodies suspended *in vacuo* and the exhausted vessel. The strength of the reaction is a measurable quantity, and hence we are able to calculate the absolute force acting on the bodies.

Description of Experiments.

The instrument best fitted for an experimental investigation of this kind is the one which has been called "Radiometer" by Mr. CROOKES. These instruments have been made in great perfection by Mr. GEISSLER, of Bonn, under the name of "Light-mills." It is needless to describe the instrument in detail, as it does not materially differ from Mr. CROOKES's radiometer. Light bodies are driven round continuously by the differential action of a source of light and heat on their faces, one of which is covered with lampblack. The motion is in such a direction that the faces covered with lampblack recede from the light when they are turned towards it. The vessel containing the "light-mill" ends above and below in a vertical tube of about 1·5 centimetre diameter. A wire was laid round the tube near the top, and then brought over the top of the vessel in such a way that it formed a hook through which a cocoon-fibre could be drawn. A concave mirror was attached to this wire. The instrument was then suspended by a bifilar suspension from the top of a glass receiver which could be exhausted. It was found, however, that the amount of air in the receiver did not affect the experiments in any way. The lower end of the "light-mill," which was suspended in this way, was dipped into a small beaker, filled with oil, in order to steady the motion of the vessel and to bring it soon to its position of rest. The azimuth of the suspended vessel was read off on a scale by means of a dot of light concentrated by the concave mirror attached to the vessel. The time of vibration of the vessel was found to be about twenty-two seconds for a complete oscillation. The logarithmic decrement was found to be about 0·176.

The beam of light of an oxyhydrogen lamp was concentrated by means of a lens, and the vessel was placed at such a distance from the focus that the cone of light just enclosed the whole of the revolving mill. In this position the instrument showed the greatest sensitiveness. The "light-mill" revolved about 200 times in one minute.

The light was cut off at the beginning of the experiment by means of a screen, and the position of rest of the glass vessel was read off by means of the dot of light on the scale. The screen was then suddenly removed, and in every case a large deflection of the glass vessel containing the light-mill was observed. The vessel was deflected in a direction opposite to that in which the mill turned. When the velocity of the revolving mill had become constant, the outer vessel gradually came back to its original position of rest. This is a fact of great importance, and considerable care was taken to find out with what degree of accuracy it could be established. Owing to disturbances produced by various causes, the zero could never be determined within two or three divisions of the scale. The position of rest of the vessel when the mill was turning with constant velocity was always found to be within that distance from the original position of rest.

When the vessel containing the rotating "light-mill" had come to rest, the screen was suddenly replaced between the light and the mill. The mill now gradually came to rest, and at the same time the vessel was driven away in the opposite direction to that in which it moved on starting the experiment. The vessel, on stopping the light, was turned in the same direction in which the light-mill revolved. I shall give the readings of three experiments taken out of a great many made at different times and with different intensity of light.

	I.	II.	III.
Position of rest (light cut off)	0	0	0
Light suddenly turned on: successive elongations of the vessels containing the light-mill	+175	+88	+144
	− 95	−31	− 51
	+ 65	+17	+ 23
	− 43	− 4	− 11
	+ 29		+ 7
Position of rest (mill turning with constant velocity) .	0	+ 2	0
Light suddenly cut off: enlongations of vessel . .	−137	−62	−127
	+ 79	+28	+ 43
	− 47	− 8	− 20

Discussion of Experiments.

In order to understand fully the meaning of these experiments I shall take the most general case, and assume that forces act on the "light-mill" which are partly internal and partly external. I call internal forces all forces which act between the mill and its enclosure. We shall find that the experiments are not compatible with the existence of external forces.

Let X_1 be that part of the internal force and X_2 that part of the external force which is independent of the velocity of the "light-mill." It is found by experiment that, however small or large the whole force is, the mill always acquires a constant velocity. This velocity increases with the intensity of the force. In order to express this condition analytically, we must assume the existence of forces which increase as the velocity increases, and which always act in the opposite direction to X_1+X_2. I shall again take the most general case, and assume that these forces, which are functions of the velocity u, are partly internal and partly external. The internal force may be expressed by

$$-\varkappa_1 f(u).$$

That part of the external force which depends on the velocity may be expressed by

$$-\varkappa_2\phi(u).$$

The whole force which possibly can act on the light-mill can therefore always be expressed by

$$X_1+X_2-\varkappa_1 f(u)-\varkappa_2\phi(u).$$

The speed at which the mill will revolve uniformly will be determined by the equation

$$X_1+X_2-\varkappa_1 f(u)-\varkappa_2\phi(u)=0.$$

The force which acts on the enclosure is equal in amount, but opposite in direction, to the internal part of the whole force. (Any direct action of the light on the enclosure is left out of account.)

The force on the enclosure is therefore expressed by

$$-X_1+\varkappa_1 f(u).$$

When u has become equal to the greatest possible speed corresponding to the whole force, this expression is proved by experiment to be zero, because then the vessel returns to the original position of rest. Hence also

$$X_2-\varkappa_2\phi(u)=0,$$

which means that no external force acts on the "light-mill," as this equation is true for all intensities of light and therefore for all values of u.

All the Forces acting on the Light-mill are internal.

The accuracy of this statement naturally rests on the accuracy with which it can be ascertained that there is no force acting on the vessel when the speed of the mill has become uniform. It can be easily seen from what I have already said about the constancy of the position of rest, and from the deflection caused by the internal forces, that the existence of an external force equal to 5 per cent. of the internal force could not have escaped observation; and had this force been even less than half that amount, it would most likely have been detected. We therefore have at present no evidence whatever of any force directly referable to radiation.

The motion in the light-mill is wholly due to the forces acting between the revolving mill and its enclosure. It has not been the object of this investigation to find out what these forces are; and I must leave it therefore to Professor REYNOLDS to show in how far the experiments agree with his theory of the phenomenon. I ought, however, to mention that on suggesting the experiments described above to him, he at once told me how the reaction would make itself apparent according to his theory. His predictions have been fulfilled throughout. It was also through his courtesy that I was enabled to work with the neat instrument made by Mr. GEISSLER, and I have had his valuable aid throughout this investigation.

It is evident that the experiments agree in detail with the fact that two internal forces exist:—one, X_1, independent of the velocity; the other, $-z_1 f(u)$, increasing as the velocity increases and acting in a direction opposite to that of X_1. The force acting on the vessel is the reaction of the force which moves the mill, and is therefore expressed by

$$-X_1+z_1 f(u).$$

As long as $z_1 f(u)$, which vanishes with u, increases, it has not yet arrived at the value given by the equation

$$-X_1+z_1 f(u)=0.$$

In that case X_1 is greater than $z_1 f(u)$ and the vessel will be impelled in the negative direction, that is, in the direction opposite to that in which the mill revolves. When the velocity of the mill has become constant, the force acting on the vessel is zero, and the vessel will therefore return to its position of rest. When the light is suddenly removed, X_1 is suddenly removed, and the only force acting on the vessel is

$$z_1 f(u).$$

This force drives the vessel round in the opposite direction, that is, in the direction in which the mill is moving. As the velocity diminishes this force diminishes until it vanishes with the velocity.

The fact that, on suddenly removing the light, the deflection of the vessel was never found as large as when the light was turned on, is easily explained. The mill acquires the maximum speed in a shorter time than that required to reduce the velocity to zero when the light is removed. The force acting up to the time of the first elongation is smaller when the light is removed than when it is turned on, and hence the smaller elongation.

Calculation of the Intensity of the Force.

As it will be useful to those who are engaged in the explanation of these phenomena to know what is the strength of the force they have to account for, I have made an approximate calculation which will at any rate give an idea of the order of magnitude of the force. From the largest deflections observed on turning the light on, I calculate that the integral couple twisting the mill round a vertical axis is equal to the couple produced by the deflection of the dot of light through 125 scale divisions, owing to the bifilar suspension. The scale was at a distance of about 1100 scale divisions from the mirror. Considering that the dot of light moves through double the angle of deflection, I find that 0·06 is too great a value for the sine of the angle of deflection. The couple produced by such a deflection is (CLERK MAXWELL, 'Electricity and Magnetism')

$$L=\frac{ab}{4h}\omega\sin\alpha.$$

In this equation a and b are the distances of the upper and lower ends of the two fibres from each other, h is the vertical distance between the lines joining these upper and lower ends, ω is the weight of the suspended body, α the angle of deflection. In the experiments we have to give the following values to these constants (the units are those of the centimetre-gramme system):—

$$a=0{\cdot}25,$$
$$b=0{\cdot}08,$$
$$h=20,$$
$$\omega=32,$$
$$\sin\alpha=0{\cdot}06;$$
$$\text{hence } L=0{\cdot}00048.$$

If p is the pressure on unit of area of the wings of the mill, A the area of these wings, and l the length of the arm of each wing,

$$L=lpA,$$
$$p=\frac{L}{lA}.$$

In Mr. GEISSLER'S light-mill, l is approximately 1·9 and $A=6{\cdot}45$*; hence

$$lA=12{\cdot}2,$$
$$p=0{\cdot}000039.$$

The pressure on one square centimetre is therefore equal to the weight of the twenty-fifth part of a milligramme, or to 0·0006 grain.

The pressure on the wings of the light-mill was equal to that produced by the weight of a film of water equal in thickness to the length of a wave of blue light. This is the greatest pressure which I have been able to produce by means of the lime-light.

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[*] This number is too large. See end of Appendix.

I have shown that an exterior force of 5 per cent. the amount of the interior force could have been detected. There cannot exist, therefore, an exterior force exerting a greater pressure on the unit of area of the light-mill than the 500th part of a milligram.

According to Prof. MAXWELL'S theory of light, an exterior force should exist; but this force would be smaller than the limits which we have given as having an appreciable effect on the experiments. By concentrating the rays of solar light in the ratio of one square foot to a square centimetre, however, the pressure on that square centimetre would be equal to 0·00004 gramme, a quantity which could not escape observation.

I think that the experiments described in the foregoing pages are interesting, not only by showing that the forces investigated by Mr. CROOKES are interior forces; but also by giving a method by means of which we are able to distinguish between such interior forces and forces directly referable to radiation. We may thus hope to find out whether such a pressure as that indicated by MAXWELL'S electromagnetic theory of light really exists.

APPENDIX (added Oct. 29, 1876).

It was suggested by Prof. MAXWELL to compare the motion of the glass vessel containing the radiometer with its equations of motion as deduced by him. I have therefore made a set of more careful experiments, and calculated from them, according to Prof. MAXWELL'S equations, the intensity of the force which acted on the vanes of the radiometer during my experiments. The number obtained has of course no other value than that of giving us an idea of the approximate magnitude of the force, as we have no accurate knowledge of the intensity of radiation actually falling on the vanes. My measurements show, however, that the motion of the vessel can be represented satisfactorily by a simple formula.

In order to deduce the equations of motion we shall, to simplify the calculation, make certain assumptions known to be only approximately correct. The first of them is, that the force acts with constant intensity during the experiments. The second is, that the resisting stress is proportional to the difference in the velocities of the radiometer and the vessel.

Let I and i be the moments of inertia of the glass vessel and of the light-mill.

Let y and x be their angular displacement.

Let $\varkappa$ be the coefficient of damping between the mill and the vessel.

Let K be the coefficient of damping between the enclosure of the light-mill and the outer vessel in which this enclosure is suspended.

Then if Hy is the force of restitution due to the bilifar suspension, the equations of motion are:—

1. For the mill

$$i\frac{d^2x}{dt^2}+\varkappa\left(\frac{dx}{dt}-\frac{dy}{dt}\right)=\mathrm{L}. \qquad (1)$$

2. For the enclosure

$$I\frac{d^2y}{dt^2}+\varkappa\left(\frac{dy}{dt}-\frac{dx}{dt}\right)+K\frac{dy}{dt}+Hy=-L. \quad \ldots \ldots \quad (2)$$

These equations can be easily integrated, yet it would be difficult to determine the constants occurring in the final equation. If we consider, however, that i is very small compared to I, and that, therefore, the velocity produced by the force L on the mill is very great compared to that produced on the vessel, we can in equation (1) neglect $\frac{dy}{dt}$ in comparison with $\frac{dx}{dt}$, and we then get as integral

$$\frac{dx}{dt}=\frac{L}{\varkappa}\left(1-e^{-\frac{\kappa}{i}t}\right). \quad \ldots \ldots \quad (3)$$

This equation means that the velocity of the mill gradually increases until it reaches the final velocity $\frac{L}{\varkappa}$. Putting the value of $\frac{dx}{dt}$ from (3) into (2), we have

$$I\frac{d^2y}{dt^2}+(K+\varkappa)\frac{dy}{dt}+Hy=-Le^{-\frac{\kappa}{i}t} \quad \ldots \ldots \quad (4)$$

The solution of this equation is

$$y=Ae^{-\lambda t}\sin(nt+\alpha)+Be^{-\frac{\kappa}{i}t}, \quad \ldots \ldots \quad (5)$$

with the conditions

$$I(\lambda^2-n^2)-(K+\varkappa)\lambda+H=0 \quad \ldots \ldots \quad (6)$$

$$2I\lambda-(K+\varkappa)=0 \quad \ldots \ldots \quad (7)$$

$$B\left(I\frac{\kappa^2}{i^2}-(K+\varkappa)\frac{\kappa}{i}+H\right)=-L; \quad \ldots \ldots \quad (8)$$

from (6) and (7) we can determine K+$\varkappa$ and I, as λ and n are found by observation, and H is given by the data of the bifilar suspension. In order to determine L from equation (8) we must find $\frac{\kappa}{i}$ and B.

For $t=0$ we have $y=0$ and $\frac{dy}{dt}=0$.

This gives the boundary conditions,

$$A\sin\alpha+B=0 \quad \ldots \ldots \quad (9)$$

$$A(\lambda\sin\alpha-n\cos\alpha)+B\frac{\kappa}{i}=0. \quad \ldots \ldots \quad (10)$$

Eliminating A and B out of these equations, we get

$$\lambda\sin\alpha-n\cos\alpha-\frac{\kappa}{i}\sin\alpha=0. \quad \ldots \ldots \quad (11)$$

It is found by experiment that after a few swings the vessel vibrates round its position of rest. The motion then is given by

$$y=Ae^{-\lambda t}\sin(nt+\alpha).$$

If the time t for the elongations is only given approximately, the elongations will determine A.

For the first elongation y_1 we have, if the time is t_1,

$$y_1=A\left[e^{-\lambda t_1}\sin(nt_1+\alpha)-\sin\alpha e^{-\frac{\kappa}{i}t_1}\right]. \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

In this equation $-A\sin\alpha$ is put for B.

Differentiating (5) we have for the first elongation, as the velocity is zero,

$$0=e^{-\lambda t_1}\{n\cos(nt_1+\alpha)-\lambda\sin(nt_1+\alpha)\}+\sin\alpha\frac{\kappa}{i}e^{-\frac{\kappa}{i}t_1}. \quad . \quad . \quad . \quad . \quad (13)$$

The equations (12) and (13) will determine t_1 and α. They can, however, be brought into a more convenient form.

Eliminating $e^{-\frac{\kappa}{i}t}$ out of (12) and (13), and introducing a new variable β, such that $\tan\beta=\frac{n}{\lambda}$, we get

$$\sin(\alpha-\beta)=\frac{-nA}{y_1\sqrt{n^2+\lambda^2}}\sin nt_1\, e^{-\lambda t_1}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

We also get easily

$$\cos(\alpha-\beta)=\frac{nA}{y_1\sqrt{n^2+\lambda^2}}\left(\cos nt_1\, e^{-\lambda t_1}+e^{-\frac{\kappa}{i}t_1}\right). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

Knowing α, we shall be able to determine $\frac{\kappa}{i}$ from (11), and hence to calculate the force L.

In the experiments actually made, 20 successive elongations were observed. It was found that after the third the vessel vibrated round its position of rest. All the elongations after the third were therefore used to determine the time of vibration and the logarithmic decrement. Another set of observations was taken after the light had been removed, and the position of rest was determined in this way for the case in which no light falls on the mill.

In the bifilar suspension the distance between the two threads at the top was 0·25, between the two threads at the bottom 0·08. The vertical distance from the top to the bottom of the suspension was 19·6, and the weight of the vessel was 31·2. The units used are those of the centimetre-gramme system. We calculate from these data

$$H=0\cdot00796.$$

We find by experiment the time of half a vibration 11·03, and the logarithmic decrement 0·02978. Hence we calculate

$$\lambda=0\cdot006219,$$

$$n=0\cdot28482.$$

Equations (6) and (7) give

$$H=I(\lambda^2+n^2).$$

Putting the value, and remembering that $K+\kappa=2I\lambda$, we find

$$\left.\begin{aligned} L&=B\left(\left(\frac{\kappa}{i}-\lambda\right)^2+n^2\right) \\ &=BH\frac{n^2}{(\lambda^2+n^2)}\frac{1}{\sin^2\alpha} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (16)$$

We now turn to the determination of B from the successive elongations of the vessel, and from the approximate time which was observed we find $A=99{\cdot}5$ in divisions of the scale. The mean of two experiments gave for the first elongation 124·3. Hence we calculate from (14) and (15)

$$t_1=9{\cdot}15$$

and

$$-\alpha=68^\circ\ 33'.$$

From this we get $B=92{\cdot}6$ in divisions of the scale. Reducing B to angular measure, we find

$$B=0{\cdot}02953.$$

The distance of the scale from the mirror was 1526 divisions of the scale. In the calculation of B we had to apply a correction, because the scale did not stand parallel to the mirror when the mirror was at rest. This was done by multiplying B with 0·9771. (This number was obtained by measuring the angle of inclination of the scale.) Putting this value of B into (16), we get

$$L=0{\cdot}0002714.$$

From (10) we get $\frac{\kappa}{i}=0{\cdot}11795$; and we have therefore now determined all the constants of the equation. In order to see in how far the values obtained correctly represent the experiments, the second elongation was calculated by the formula to be 172·3 divisions of the scale. By experiments it was found to be 171. As the second elongation did not enter into any determination of the constants, the agreement seems satisfactory.

Calculating the position of rest from the successive elongations when the mill was turning, and afterwards when the mill was at rest, a difference of 1·3 division of the scale was noticed. The vessel appeared to be deflected 1·3 division of the scale in a direction opposite to that in which the mill was turning. Considering the difficulty which besets the exact determination of the zero-point when the light is turned on the mill, owing to changes in the intensity of the light, external air-currents, &c., we may regard the two positions of rest to be, as far as our experiment could determine them, identical. The permanent deflection either way, if it existed, must, we may say with certainty, have been smaller than 5 divisions of the scale.

The moment of any external force, if existing, must therefore have been smaller than 0·000013, or less than 5 per cent. of the internal force.

In order to get a numerical value for the pressure on the unit of area of the wings of the mill, we must divide the couple L by the length of the arms and the area of the wings. The length of the area was approximately 1·9 and the area 4·84; hence the pressure on a square centimetre during the experiments was

$$0·000030 \text{ grammes},$$

which is equal to the weight of a layer of water covering the surface, and equal in thickness to the length of a wave of ultra-violet light. The pressure is about double that determined by Mr. CROOKES in one of his experiments*. Considering the greater intensity of the light used in my experiments, the results agree pretty well with each other.

In the original paper the area of the wings was erroneously given as 6·45; the pressure was therefore found too small in the proportion of 4·84 to 6·45. The pressure deduced by the rough method of the original paper should therefore have been

$$p=0·000052.$$

The number only professed to be an outer limit to the pressure, the real pressure being necessarily smaller. The intensity of the light used in the more careful experiments described in these pages was decidedly smaller than that used in the original experiments. Under these circumstances I think the agreement between the two numbers is as close as could be expected.

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* Lecture delivered at the Royal Institution, February 11; reprinted, 'Quarterly Journal of Science,' April 1876.

XXVIII. *On the Forces caused by the communication of Heat between a Surface and a Gas; and on a new Photometer.* *By* Prof. Osborne Reynolds. *Communicated by* B. Stewart, *F.R.S., Professor of Natural Philosophy in Owens College, Manchester.*

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In a paper read before the Royal Society[*], April 1874, I pointed out that the communication of heat from a solid surface to a gas, whether accompanied by evaporation or not, must, according to the kinetic theory, be attended by a reactionary force equivalent to an increase in the pressure of the gas on the surface, and, conversely, when heat is communicated from the gas to the surface the pressure against the surface is diminished; and I also suggested that these forces are the probable cause of the motion, resulting in some way from radiation, which Mr. Crookes had brought into such prominent notice.

Since the publication of this paper neither my conclusions as to the existence of these "heat reactions," nor the reasoning by which I supported them, have been controverted or even questioned; but, on the other hand, they have received important confirmation. The results at which Professors Tait and Dewar arrived after a careful investigation fully bear out my conclusions, not only as to the existence of the forces, but also as to the way in which they explain Mr. Crookes's experiments.

Still it seemed desirable, if possible, to settle the question by obtaining such quantitive measurements of the effects produced as would show whether or not they agreed with what might be expected from theoretical considerations. I have accordingly been on the look-out for some means of making these experimental verifications. Such a means I at length found in one of the beautiful little instruments constructed by Dr. Geissler, of Bonn, after the manner of Mr. Crookes, and called by him "Light-Mills." As this instrument has taken an important part in the experiments I have to describe, I shall commence by giving a detailed description of it.

The Light-Mill.

This consists of a glass envelope in the shape of a pear, about $2\frac{1}{2}$ inches through its thickest part; standing up from its lower end is a steel needle, coincident with its axis. On the top of this needle is balanced (after the manner of a compass-card) the mill or wheel; this consists of a small central glass cup which rests on the point of the needle, and to which are fused four very thin platinum arms, which have their outer ends attached to four square plates (which appear to be talc or mica-schist) $\frac{1}{2}$ inch square, fastened so as to stand vertically with a corner at the top. The distance of the centres of these plates from the axis is about $\frac{3}{4}$ of an inch. The plates are very thin, and are covered on one of their sides (which sides are all turned the same way) with lampblack.

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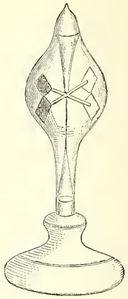
[*] Roy. Proc. 1874, vol. xxii. p. 401.



Descending from the top of the vessel is a small tube, the function of which is to keep the wheel from falling from its pivot when the instrument is turned over. The air within the mill has been greatly rarefied; electricity will not pass; but more than this I cannot say.

The Action of the Light-Mill.

When placed in the light the mill quickly arrives at its maximum speed, and rotates continuously with a velocity depending on the intensity of the light. It will rotate steadily at speeds varying from 1 revolution in 6 minutes (in the light of the full moon) to 240 revolutions in a minute (in the strongest light I have been able to obtain).

When the mill is revolving, and the light is suddenly extinguished, it rapidly comes to rest.

These two facts, namely (1) that the mill rapidly arrives at its maximum velocity when the light is turned on, and (2) that it as rapidly comes to rest when the light is turned off, are those to which I wish first to direct attention, for they appear to me to prove conclusively that *the air within the envelope does exercise influence on the mill.*

(1) If it were true, as has been supposed, that the best results are obtained in a vacuum so perfect that there is not sufficient air to exercise any influence on the vanes of the mill, then it follows that the mill would move without experiencing any resistance from the air, and the only known resistance would be the friction of the pivot. Now whether or not this is the case is easily ascertained. The resistance of the pivot, whatever may be its magnitude, does not increase with the speed of the mill, and hence does not oppose a greater resistance to its motion when it is turning fast than when it is turning slowly. The friction of the air, on the other hand, increases rapidly with the velocity. There is therefore a difference in the manner in which these two resistances will affect the motion of the mill. If the mill were only subject to the resistance of the pivot, any force which would start it would continue to turn it with increasing velocity as long as it acted; whereas, when subject to the resistance of the air, the resistance increasing with the speed, the mill would soon arrive at such a speed that the resistance balanced the turning force; after which the motion would be steady. This difference in the action of the friction of a pivot and that of the air is well known in mechanics and utilized, as, for instance, in the striking part of a clock. If prevented by nothing but the friction of the spindles when the clock is striking 12 say, each stroke would follow after a less interval than the previous one. Now the invariable means by which this is prevented is by a fan like the wheel in the light-mill, which, by the resistance it experiences in moving through the air, prevents the clock striking at more than a certain rate.

Now, from the description of Mr. CROOKES's instruments which he has published, it appears that they, like the one which I possess, arrive at a constant velocity depending on the intensity of the light. Hence it may be fairly inferred that in them the motion of the wheel is restrained by the same resistance as in mine; and that this resistance, as I have just shown, is not the resistance of the pivot.

(2) The limited velocity of these mills is therefore exactly what would be caused by the friction of the air, just as in the clock: but there is another conceivable cause of the limit; and this is, that the force which causes the motion diminishes with the velocity. Fortunately, however, there is another test by which the resistance may be examined, a test altogether independent of the action of light or heat. This is the rate at which the mill comes to rest when the light is turned off. If the pivot were the only source of resistance the time required for the mill to come to rest would be as the speed; that is to say, if it required 15 seconds for the mill to come to rest when making 10 revolutions per minute, it would require 150 seconds to come to rest from 100 turns per minute. In fact, however, my mill, which requires 15 seconds to come to rest from 10 revolutions, does not take 30 to come to rest from 100 revolutions. In these experiments the wheel was set in motion by turning the envelope, and not by the aid of light or heat. We have, therefore, conclusive evidence that the resistance is not merely that of the pivot (which, in fact, is so small as to be inappreciable); and the only other resistance of which we know* is that of the air. But this is not all.

The behaviour of the mill furnishes us with the exact law of the resistance; and this is identical with the law of the resistance of air in a highly rarefied condition, a law distinctly special in its character.

The resistance which bodies experience in moving through the atmosphere at considerable velocities is proportional to the square of the velocity; but if the velocity is very small, less than one tenth of a foot per second, then, as Prof. STOKES has shown, the resistance is nearly proportional to the velocity. Now, so far as this latter resistance goes, Prof. MAXWELL has shown the singular fact that, although it depends on the nature, it is independent of the density of the air or gas. A body moving at a very small velocity would therefore experience the same resistance whether moving outside or within the receiver of an air-pump in which the air was highly rarefied, the only difference being that the speed for which the resistance continues proportional to the velocity is higher in proportion as the tension of the air is reduced.

If, therefore, the vanes of the light-mill were moving in air as dense as the atmosphere they would experience a resistance increasing with this speed according to a law varying from the velocity at low speed to the square of the velocity at high speeds; but since they move in an exceedingly rare medium, the resistance which it offers is more nearly proportional to the velocity throughout, and only at the highest speeds can there be any appreciable deviation from this law.

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* Ethereal friction, if it exists at all, must be too small to produce any appreciable effect, and it is not probable that it would follow the same law as air.

The limit which this resistance would impose on the speed would, at low speeds, be very simple; the velocity would be proportional to the force causing it.

If the light from each of two candles would cause the mill to turn with a certain velocity, then the two candles acting together should cause the mill to turn with double velocity; and this is exactly what happens, as the following Table shows:—

Distance from the candles in feet.	Number of revolutions per minute.	
	1 candle.	2 candles.
2	1·2	3
1	$5\frac{1}{2}$	11
$\frac{1}{2}$	23	36
$\frac{1}{4}$	65	120

It will be seen that at very small velocities the effect of 2 candles is rather more than double that of 1; this is owing to the friction of the pivot, which is constant.

Also at the higher velocities there is a falling off in the speed, exactly as might be expected from the air. Hence we see that the force which limits the speed of the mill, follows the same complicated law as that of the resistance which would result from the friction of the air; and hence there cannot be a doubt but that they are the same.

The Force which turns the Mill is not directly referable to Radiation.

With reference to the assumption that the force is radiant or in any way *directly* referable to radiation, I pointed out at Bristol, before Section A (Brit. Assoc.), that in any such supposition the results of the experiments are directly opposed to one of the fundamental laws of motion, viz. that action and reaction are equal. In these experiments a hot body causes a cold body to recede, while a cold body causes the hot body to approach; so that if both the bodies were free to move, we should have the cold body running away and the hot body running after it. This fact is, I take it, a conclusive proof that the force does not act from body to body, but between each body and the medium in which it is placed; that each body, as it were, propels itself through the surrounding medium in a direction opposite to its hottest side.

The truth of this reasoning has been set beyond all doubt by a very beautiful experiment made by Dr. SCHUSTER. The results of this he is about to communicate to the Royal Society; and as his paper will contain a full account of the experiment, it is only necessary here for me to refer to the results and the way in which they bear on the subject in hand. Dr. SCHUSTER suspended my light-mill by a double fibre, so that if undisturbed by any torsional force it would hang with the vessel always turned in one direction, but in such delicate equilibrium that the smallest torsional force would cause it to take a fresh position. In this way he was enabled to ascertain whether the action of light on the vanes of the mill was attended with any effect to turn the envelope.

Some such effect must have been caused whatever had been the nature of the force, either in the commencement or in the maintenance of the motion.

For, in the first place, if the force acting on the vanes arose from an external source, then the vanes in turning, owing to the friction of the pivot and the friction of the air, must tend to drag the envelope round with the mill; consequently, on the light being turned on, the envelope would have turned in the same direction as the vanes, and continued to do so until the torsion of its suspension had restrained its further motion: it would then have remained steady until the light was turned off, when it would have come back to its former position.

Whereas, on the other hand, if the force on the vanes arises entirely within the vessel, if the air is, as it were, the fulcrum against which the force acts, then, in order to overcome the inertia of the vanes and set them in motion, the air must itself move in the opposite direction, just as when a steamboat starts it sends a stream of water backwards. This motion of the air will be communicated by friction to the vessel, and the effect will be that on the light being turned on the envelope must turn in the opposite direction to the vanes; that when the mill has acquired its full speed then, as in the case of a steamboat, the backward motion given to the fluid by the propellers will just balance the forward motion imparted by the resistance of the ship, and the resultant force will be nothing. When, therefore, the mill has acquired its full speed the envelope will come back to its normal position, where it will remain until the light is turned off, when the friction acting alone will tend to drag the internal fluid and hence the envelope forward.

This was the view of the case which I took when Dr. SCHUSTER first suggested his experiment to me; and when it came to be performed the results, as may be seen, were in strict accordance with the second supposition, namely, that the force acts entirely between the vanes and the air within the mill.

This experiment of Dr. SCHUSTER's also afforded a means of arriving approximately at

The Magnitude of the Force.

The weight of the mill and the envelope, considered in conjunction with its manner of suspension, gave the moment of the torsional force necessary to turn it through an angle of ·06 as ·0000000264 lb., or one forty-millionth part of a pound acting on a lever a foot long. To cause this deviation the light had to be such as would cause the vanes to make 240 revolutions per minute. Hence, when making 240 revolutions per minute, we have a measure of the force which causes the motion and the resistance which opposes it. Now considering that the centres of the vanes are $\frac{3}{4}$ inch from the axis, the whole force acting on the vanes will be $16 \times ·0000000264$ of a pound,—that is ·00000042, or one two-million-five-hundred-thousandth part of a pound; this distributed over the vanes (whose joint area is 1 sq. inch) is ·00000042 lb., or one two-million-five-hundred-thousandth part of a pound on the square inch. And assuming that the tension of gas within the mill is ·0005 lb., or one two-thousandth part of a pound on the square inch (the tension of a toricellian vacuum at 60° F.), *then we see that the difference of pressure on the two sides of the vanes is* ·0008 *of the pressure within the mill, or less than one thousandth part.*

These results, although they do not pretend to be more than approximate, show how exceedingly small is the real effect, and they place these phenomena of motion caused by heat in a light from which the exceeding delicacy and sensitiveness of the instruments have altogether withdrawn them.

The difference of Temperature.

Having obtained these measurements of the force, it remained to see what difference of temperature would be necessary, according to the kinetic theory, that the reaction from the communication of heat might equal these forces, and then to ascertain how far such a difference of temperature actually existed. To do this I have had to enter upon new and somewhat doubtful ground: however, I venture to submit the following, which, although it contains assumptions, contains none but what are legitimate and strictly in accordance with the kinetic theory.

Theoretical Difference of Temperature.

Whatever may be the nature of the action by which heat is communicated from a surface to a gas, the result, according to the kinetic theory, is to increase the mean square of the velocity with which the molecules move in the ratio of the temperature: thus, if v be the initial velocity, and τ the initial absolute temperature, and if

$$v^2 = A\tau,$$

where A is a constant depending on the nature of the gas, then

$$(v+dv)^2 = A(\tau + d\tau),$$

or, neglecting dv^2 as a small quantity,

$$A d\tau = 2v dv,$$

$$d\tau = 2dv\frac{\tau}{v}.$$

Now, if we assume that each molecule comes up to the surface with a velocity v, and leaves with a velocity $v+dv$, we shall have the greatest reactionary force which it is possible that the heat could produce. That the force produced is as large as this is not probable. We know that at ordinary densities the molecules communicate the heat to each other, so that they do not come up to the surface with so small a velocity as v. The smaller the tension of the air, however, the less will be the difference; so that the force which we have assumed is the limit towards which its force tends as the vacuum improves, so long as the conditions of a perfect gas are fulfilled*. The increase dv in the velocity with which the molecules leave the surface would increase the pressure in the ratio

$$\frac{2v+dv}{2v},$$

or

$$\frac{p+dp}{p} = 1 + \frac{dv}{2v},$$

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* Proc. Roy. Soc. 1874, vol. xxii. p. 407.

$$\therefore \frac{dp}{p}=\tfrac{1}{2}\frac{dv}{v};$$

and by the foregoing

$$\frac{dv}{v}=\tfrac{1}{2}\frac{d\tau}{\tau},$$

$$\therefore \frac{dp}{p}=\tfrac{1}{4}\frac{d\tau}{\tau}.$$

Therefore if, as we have calculated,

$$\frac{dp}{p}=\cdot 0008,$$

$$\frac{d\tau}{\tau}=\cdot 0032,$$

and taking $\tau=520°$ F.,

$$\therefore d\tau=1\cdot 6640.$$

If, therefore, the difference of temperature caused by the light were not greater than 1°·7 F., it would appear from these measurements that the forces arising from the communication of heat would not be adequate to cause the effect produced. That is to say, 1°·7 is the lowest limit that the theory admits for the heat reaction to have caused the effects in this particular case. The theory points to the probability, however, that the difference was considerably greater than 1°·7.

To put this to the test it was necessary to obtain some measure of the

Actual Difference of Temperature on the Black and Bright sides of the Plates.

So far as I am aware there is no recognized means of measuring this difference; and although it is admitted that a black surface exposed to light will attain a higher degree of temperature than a white or bright surface, no comparative experiments have been made.

While taking part with Dr. SCHUSTER in his experiments, I held an ordinary thermometer containing some dark red fluid in the place which the mill had occupied exposed to the light. This came from a lime-light, and was condensed by an ordinary lantern.

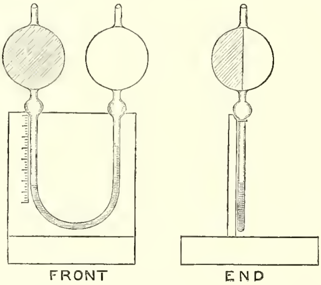
The thermometer rose to 130° F., and was still rising when the experiment had to be discontinued.

This measure, great as it was, was not satisfactory, for it was not comparative, and a white-bulbed thermometer would obviously have risen to some extent. I therefore took two similar mercurial thermometers, blackened the bulb of one and whitened that of the other, and exposed them to similar intensities of light. Under all circumstances the black bulb was the most affected, for however long a time the exposure was continued; the light of a candle which caused the light-mill to make 30 turns per minute made a difference of $2\frac{1}{2}°$ in the thermometers, whereas a feeble sun, which gave the mill about 60 turns, caused a difference of 5°. These results showed a close agreement with the action of the light-mill; but whereas the light acted instantaneously on the mill, the thermometers did not show signs of moving for some time. It also seemed probable that the immediate surface which was exposed to the light, besides coming to its temperature almost instantaneously, would probably assume a higher temperature than that which would be communicated through the material. In order to show this it occurred to me to construct

A New Photometer.

This instrument consists of two very thin hollow glass globes, $2\frac{1}{2}$ inches in diameter, connected by a siphon-tube $\frac{1}{8}$ inch internal diameter.

One of the globes was blackened *on the inside* with lampblack over one hemisphere, and the other was whitened with chalk in a similar manner; the siphon-tube was filled with oil, the air within the globes was carefully dried, and they were sealed. The two clean sides of the globes are turned in the same direction, so that any light entering through these clean sides falls equally on the blackened and whitened surfaces within. The air within instantly commences to receive heat in proportion to the temperature of these surfaces, and, expanding, moves the liquid in the tube.



By comparing the volume of a certain length of the tube with the volume of the globes, the distance which the liquid moves for 1 degree difference of temperature has been found: 1 inch means 2·2 degrees. A scale having been fixed to the tube, the effect of light to cause a difference of temperature in the air can be read off.

There is, however, still one difficulty: the air within the globes does not arrive at the temperature of the surfaces, as these do not entirely enclose it. All that can be said is that it is proportional, probably about $\frac{1}{4}$ or rather more.

This difference may, however, be set off against the difference which must exist in the mean temperature of the vanes of the mill, and what it would be if they remained steadily perpendicular to the light. As it is, each part of the surface of the vane is only exposed to the light for half its time, and then at varying angles; so that the light that it receives bears to the light which would fall on it, if fixed and perpendicular, the ratio of the diameter to the circumference of a circle, *i. e.* the ratio $\frac{1}{\pi}$. In the case of the photometer the ratio of the section of the intercepted beam to the whole surface of the sphere is that of the area of a great circle to that of the sphere, or $\frac{1}{4}$; so that it is probable the photometer only registers $\frac{3}{4}$ the difference of temperature which similar surfaces would acquire on the mill.

The white surfaces on the mill, however, are not similar to those of the photometer, and they probably absorb considerably more light, and consequently diminish the difference of temperature; so that, on the whole, it is probable that the differences recorded by the photometer are quite as great, if not greater than those which exist in the mill.

The instrument is very sensitive, and begins to move as soon as the light falls on it. Its indications agree surprisingly with those of the light-mill: 1° on the photometer corresponds with 11 revolutions per minute of the mill. When the mill made 200 revolutions per minute, the reading on the photometer was 21°, which is the highest it will record. Differences to $\frac{1}{10}$ of a degree can be read on the photometer, or the effect of light which will turn the mill at 1 revolution per minute. It can be used, therefore, for all purposes of photometry for which the mill may be useful. It is much more convenient, as it requires no counting, and it can be made with much less trouble.

Measured by this photometer, the difference of temperature in Dr. SCHUSTER's experiment would have been 24°. This, which must be looked on as an outside measure, leaves ample room for allowance for the inaccuracy of the calculation. We have, on the one hand, the least estimated heat 1°·7, and the greatest limit of the measured heat 24°, and the probability that both these quantities tend towards each other.

Conclusion.

The investigation of which this paper gives an account was undertaken with a view to settle the only point respecting my previous explanation of the motion caused by heat which appeared to me to remain doubtful, after I had discovered that, according to the kinetic theory, the communication of heat to a gas was attended by a reaction on the surface, viz. whether this reaction was adequate in amount to produce the motion. This point has now been cleared up. We have:—

1. The remarkable agreement between the law of the resistance experienced by the mill and the peculiar law of the resistance which air offers at small tension.

2. Dr. SCHUSTER's positive proof that the force which acts on the vanes arises within the mill itself.

3. The exceedingly small magnitude of the actual force, as shown by quantitive measurements.

4. The fact that the estimated difference of temperature necessary to produce heat-reactions of equal magnitude with the forces which act is well within the difference of temperature actually found to exist.

Taking all these facts into consideration, it seems to me that the evidence is conclusive as regards the nature of the forces which cause the motion in light-mills, and that we may now look upon the motion caused by light and heat as a direct proof of the kinetic or molecular theory of gas.

A new Light-Mill.

Although the proofs against the forces in the light-mills being directly referable to radiation are already more than sufficient, I will venture to suggest one more test, which the difficulty of obtaining the instrument has as yet prevented me applying. If a "light-mill" were made unlike those which have hitherto been constructed, inasmuch that, instead of its vanes being perpendicular to the direction of motion, and having one side black and the other white, it has vanes arranged like the sails of a wind-mill or the screw of a ship, all inclined to the direction of motion, and of the same colour on both sides; then if this mill turned, it would show that the force is not influenced by the direction from which the light and heat come, but that, like the wind on a wind-mill, it acts perpendicularly to the surface of the vanes*.

It seems to me that, inasmuch as the vanes of such a mill would be continuously acted upon, and would experience the full and not merely the differentiated effect of light, it would be much more sensitive than those at present constructed.

APPENDIX (March 7, 1877).

Vanes fixed in the Envelope.

In the discussion which followed the reading of this paper, it was stated by Mr. CROOKES that he had suspended his instruments upside down by a single fibre, and floated them upside down in water, and had then found, when the vanes could not turn in the envelope, that the whole envelope rotated very slowly under the action of light, steadily and continuously in the same direction as that in which the vanes would have turned had they been free. And at the Meeting on March 30th, subsequent to the reading of this paper, Mr. CROOKES described how the case of one of his instruments floating in water revolved at a rate of about 1 revolution an hour when the vanes were free to turn. Comparing this effect with that which was caused when the vanes were fixed by the magnet one revolution in 2 minutes, it appears that the force turning the envelope with the vanes free was $\frac{1}{30}$th that turning the vanes; for the resistance of the water at such small velocities would be proportional to the velocity.

As no such effect to turn the envelope had been observed during Dr. SCHUSTER'S experiment, in which I took part, and as it was difficult to conceive any method of suspension more delicate than that then adopted, I was forced to believe that the effect found by Mr. CROOKES was due to some accidental cause, such as air-currents, about the outside of the case of his mill. I therefore repeated Mr. CROOKES's experiment; first, by floating the mill, as he describes, in a beaker of water, and simply covering the whole with a glass shade. I then found that it was impossible to bring sufficient light to bear on the mill to cause the vanes to revolve without causing the case to turn; although this turning was irregular, and such as might be caused by air-currents. Dr. SCHUSTER and myself then suspended the same light-mill we had previously used in a manner in all respects similar to that of his former experiments, except that the mill was upside down, so that the vanes could not turn in the envelope. On the light being turned on a certain amount of disturbance was always consequent so long as the receiver was not exhausted; but when the receiver was exhausted to about $\frac{1}{2}$ inch of mercury, no motion at all could be observed. At the soirée given by the Royal Society on the 14th of June, 1876, I had two mills suspended, the one upright and the other reversed. The envelope of the upright mill moved when the light was turned on through a distance represented by several hundred divisions of the scale; but the reversed mill showed no motion at all, although a motion of two divisions must have been perceived. The mills were suspended in vessels from which the air had been pumped until the pressure was about half an inch of mercury. In these experiments, therefore, there was no residual force tending to turn the envelope with the mill so great as $\frac{1}{100}$ the force on the mill.

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* In the discussion which followed the reading of the paper, Mr. CROOKES mentioned that he had already constructed mills with inclined vanes, and found them answer; and I am informed that he exhibited one at the next meeting of the Society. I may mention here that I have received a mill from Dr. GEISSLER, which I had previously ordered. This instrument, although damaged in transit, is sufficiently sensitive to prove that the action of heat is altogether independent of the direction from which the heat comes.—July 31, 1876.

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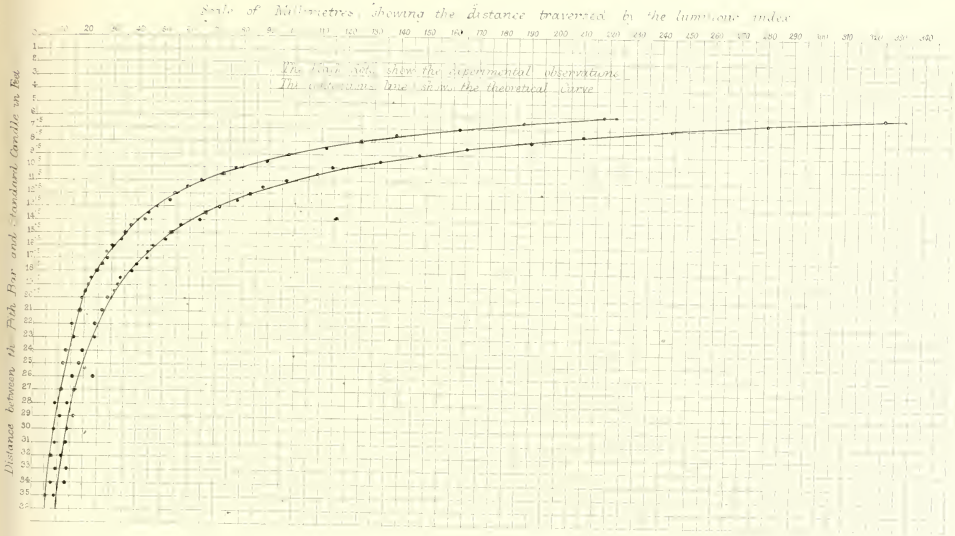
FIG. 4



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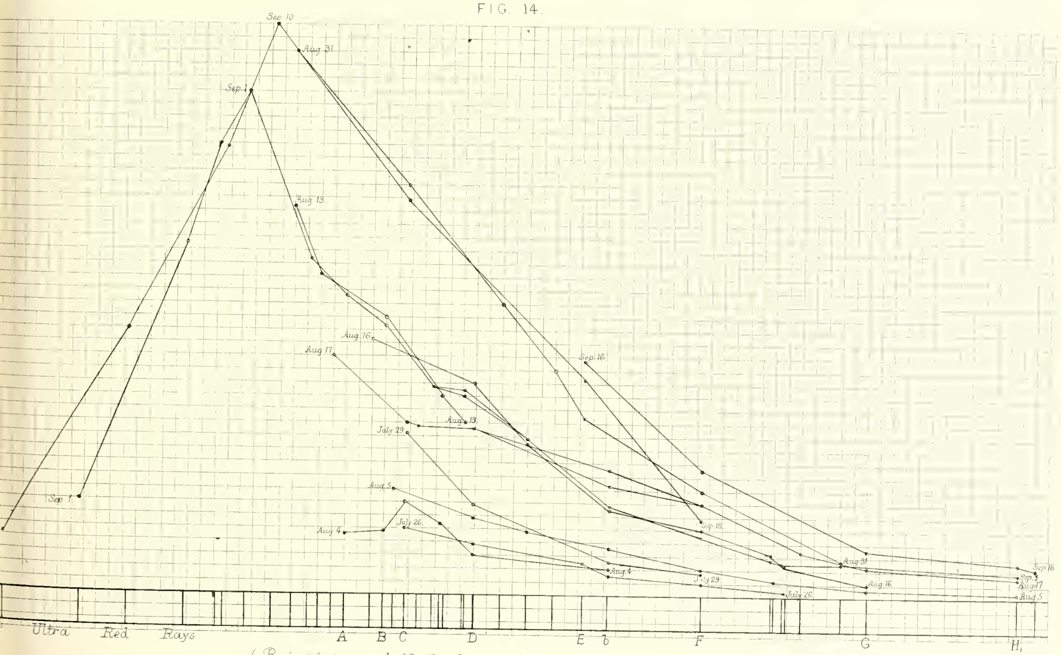

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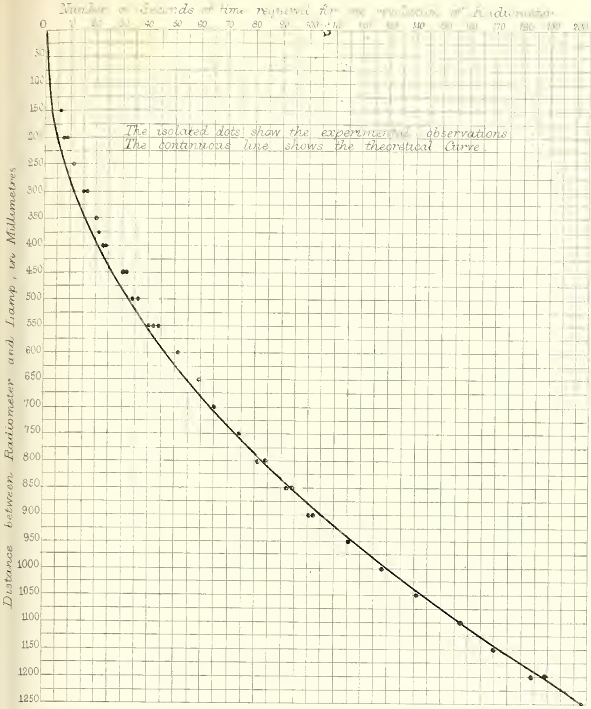
FIG. 7



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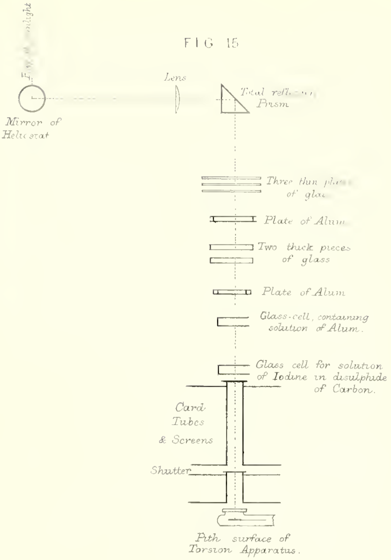
Sunlight
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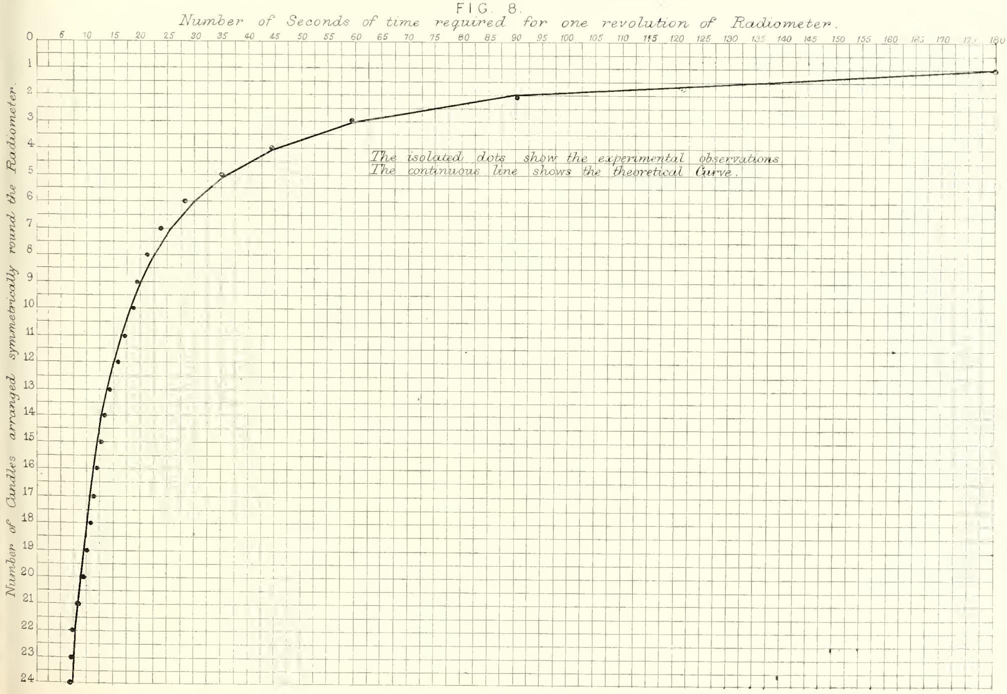
Total reflecting Prism
Mirror of Heliostat
Three thin plates of glass
Plate of Alum
Two thick pieces of glass
Plate of Alum
Glass-cell, containing solution of Alum.
Glass cell for solution of Iodine in disulphide of Carbon.
Card Tubes & Screens
Shutter
Pith surface of Torsion Apparatus.

FIG. 8.



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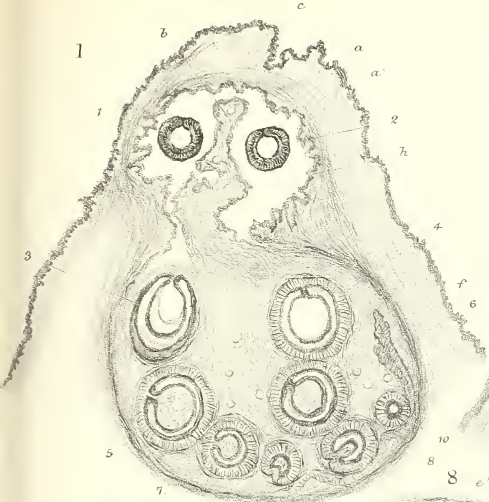
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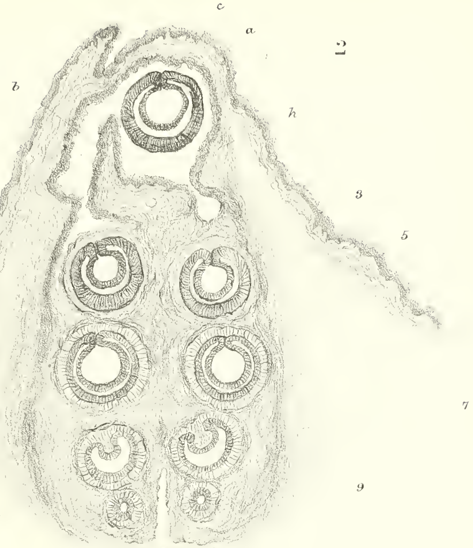
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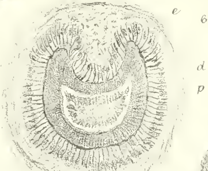
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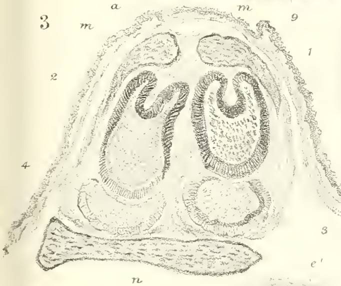
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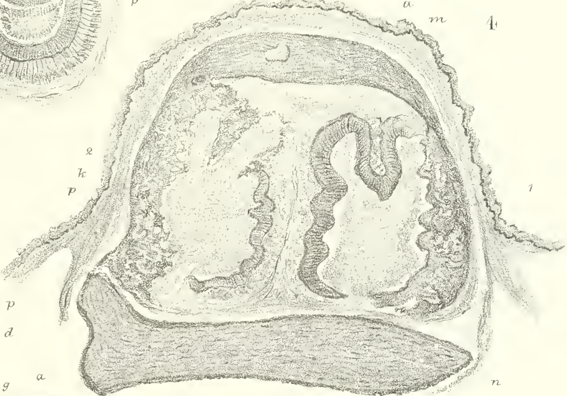
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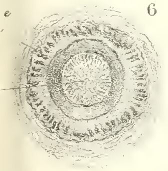
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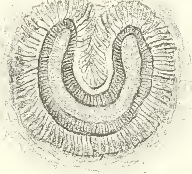
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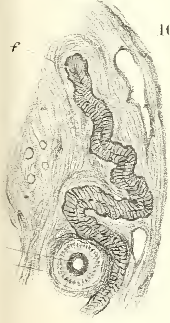
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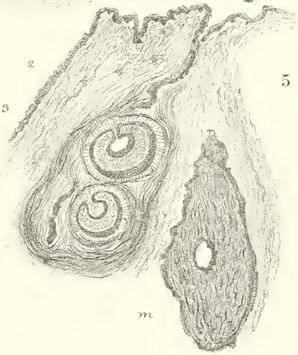
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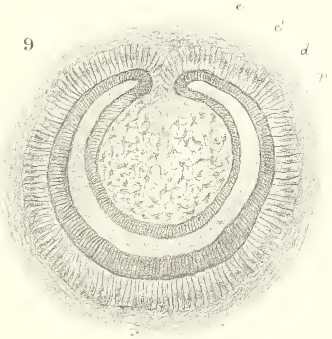
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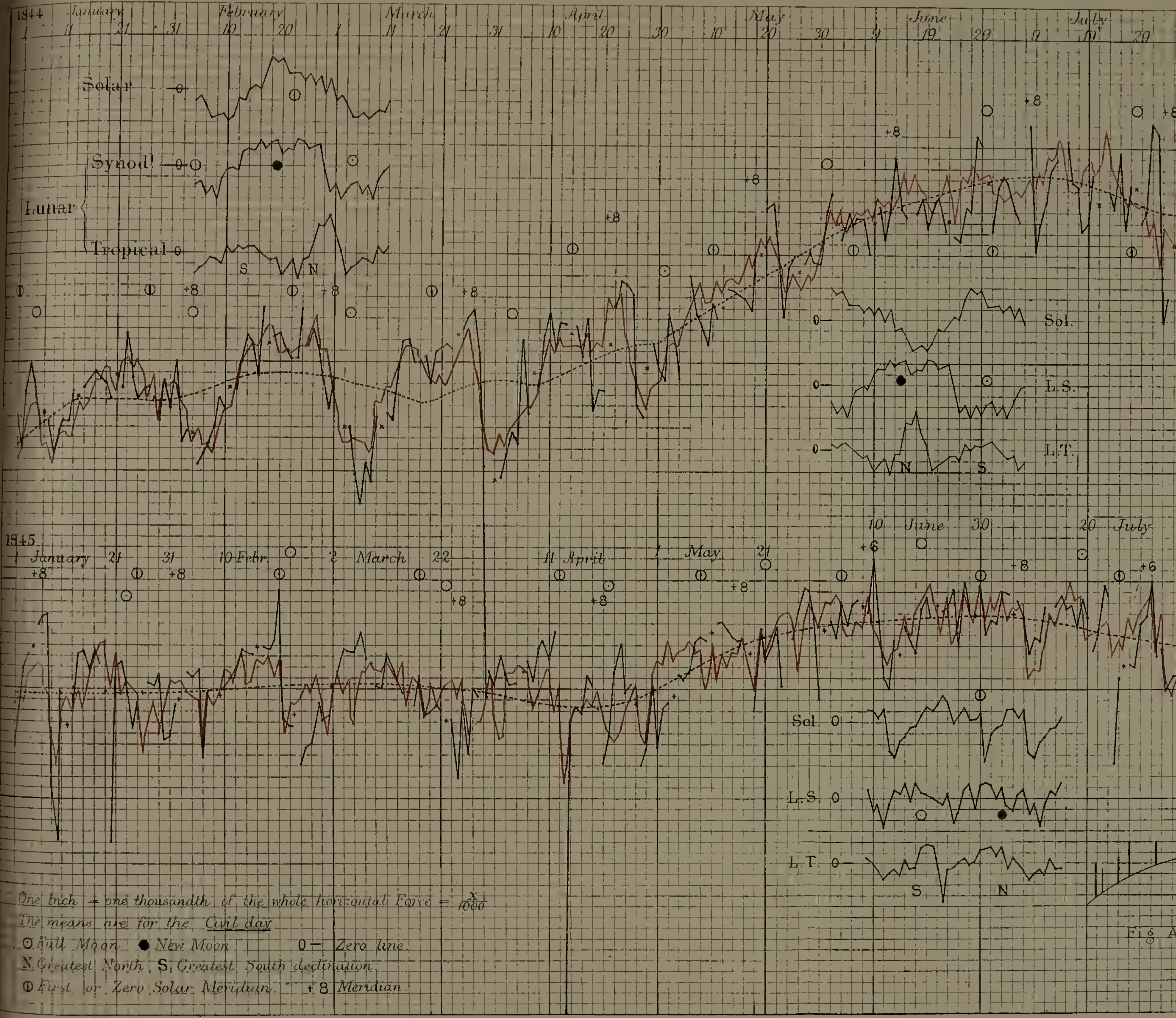
Daily means of the horizontal Force of the Earth's Magnetism for the years 1844 and 1845, as deduced from the



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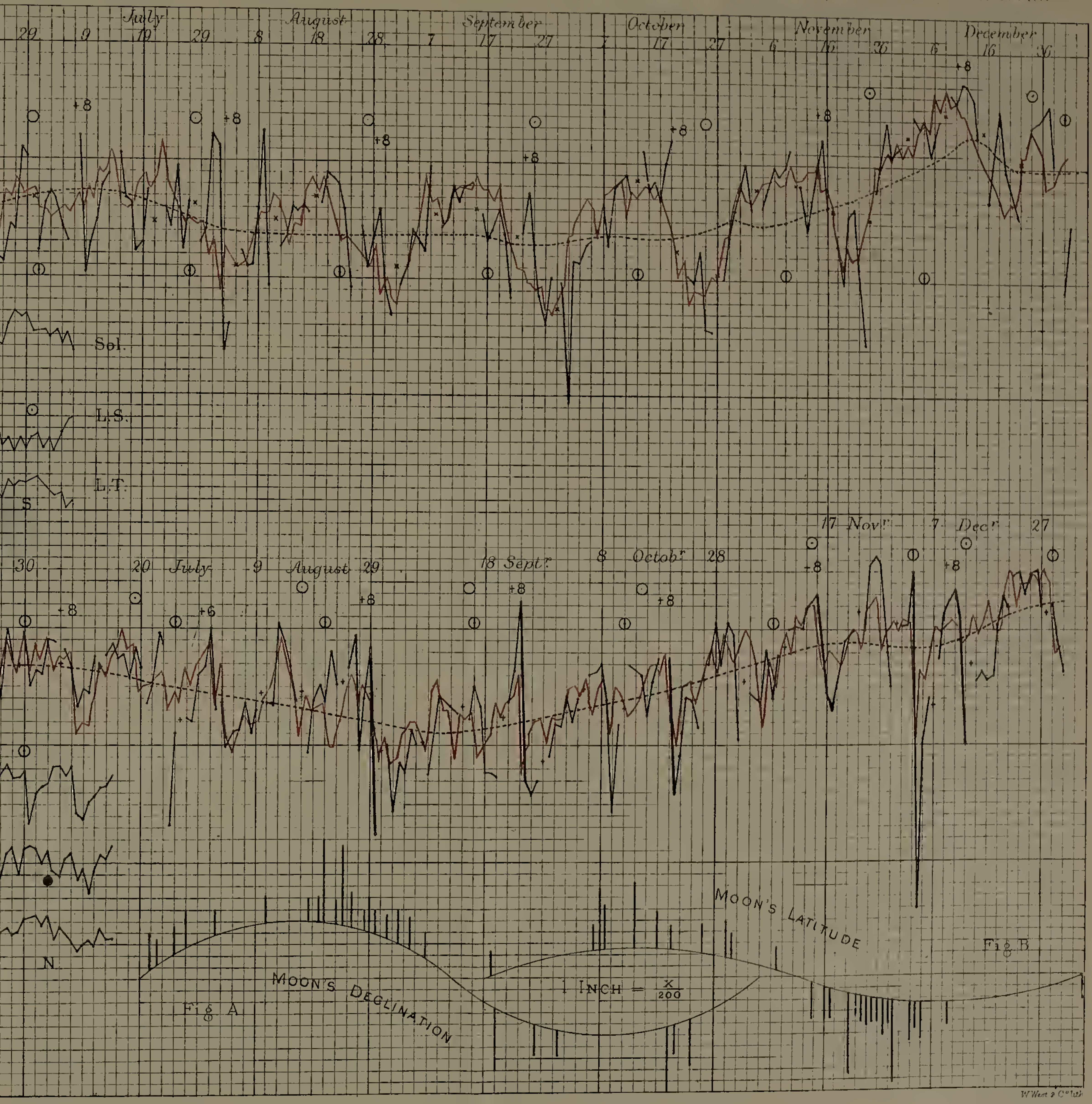

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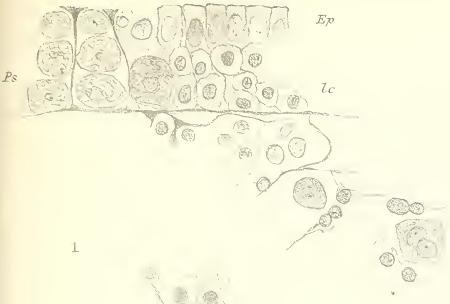

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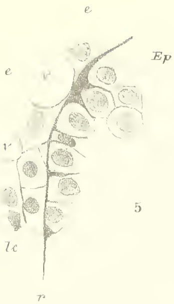

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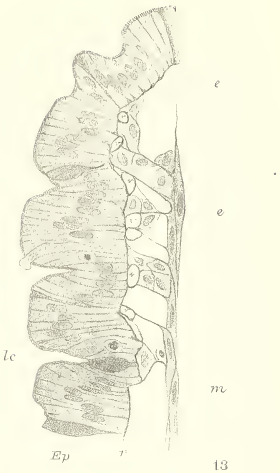

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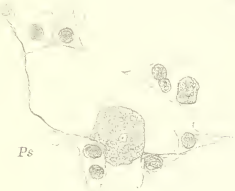

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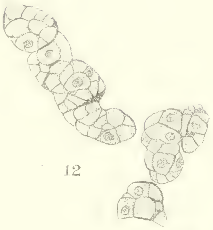

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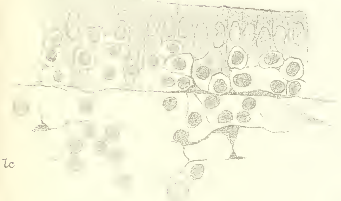

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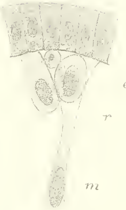

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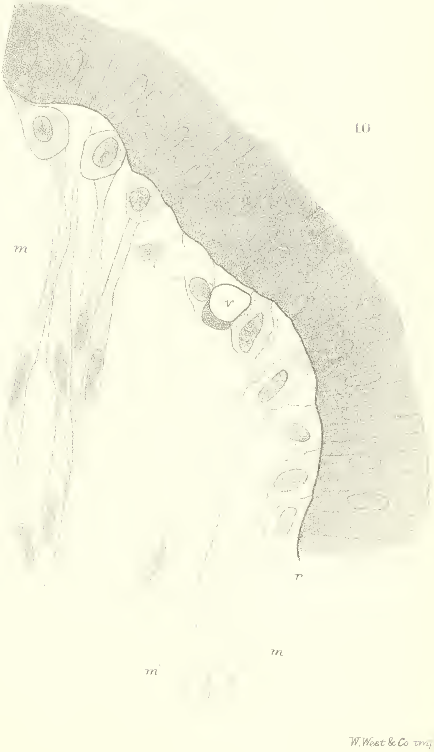

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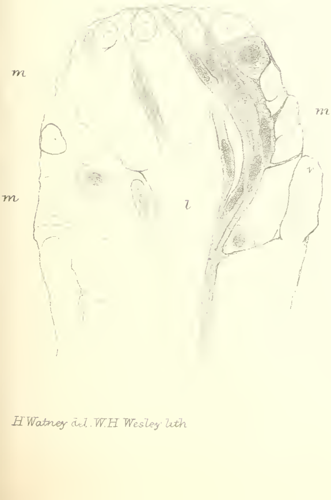

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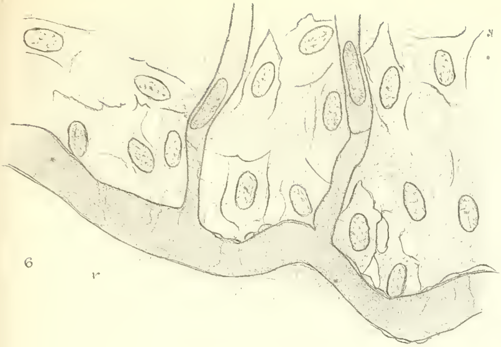

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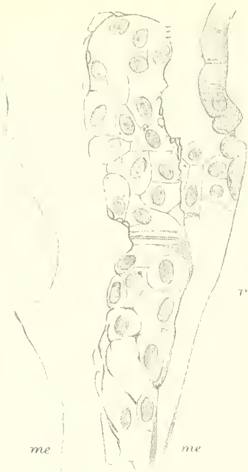

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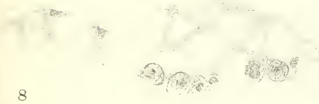

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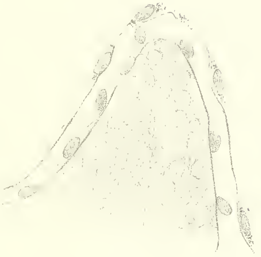

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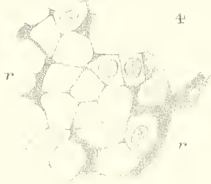

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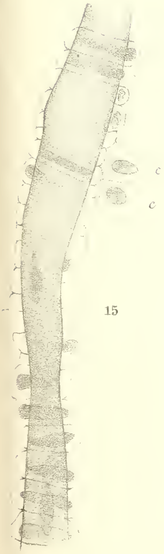

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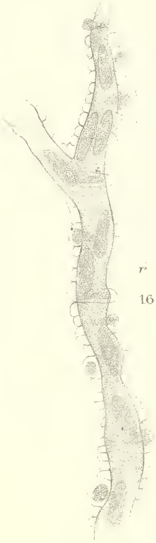

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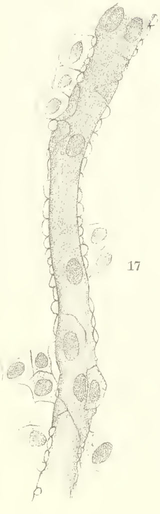

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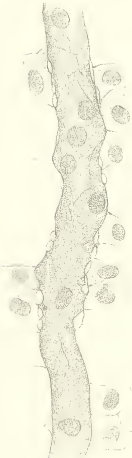

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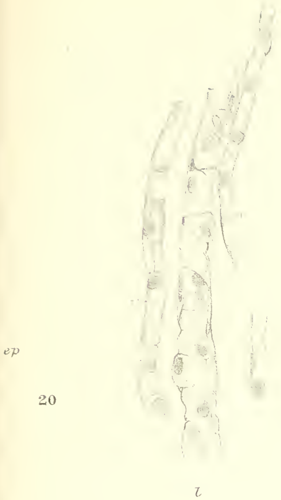

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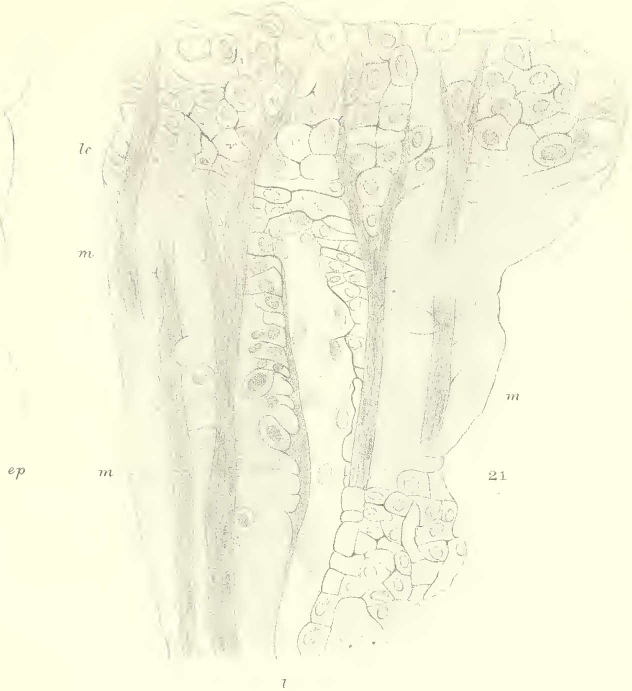

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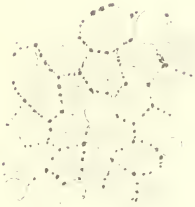

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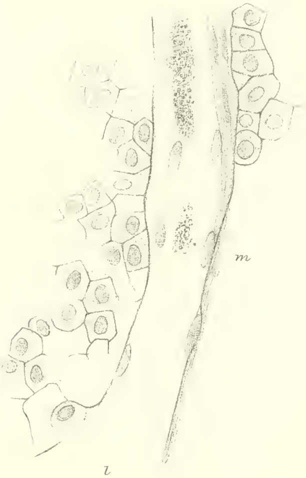

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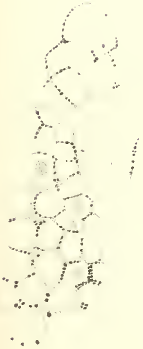

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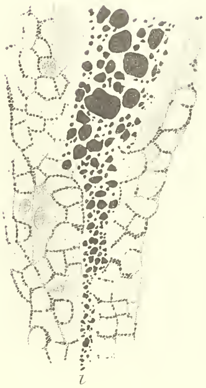

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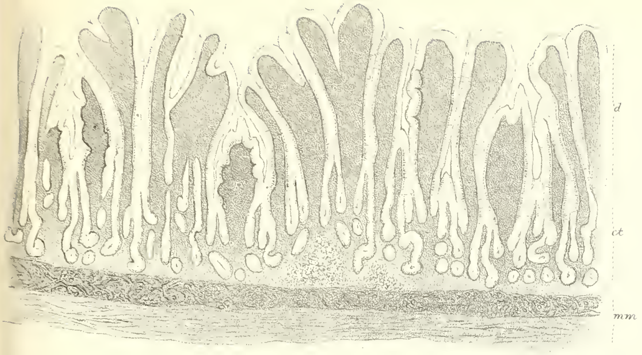

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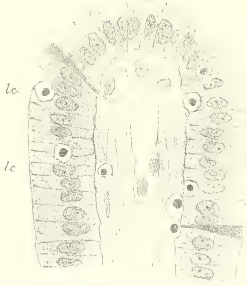

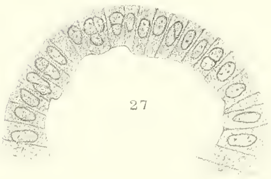

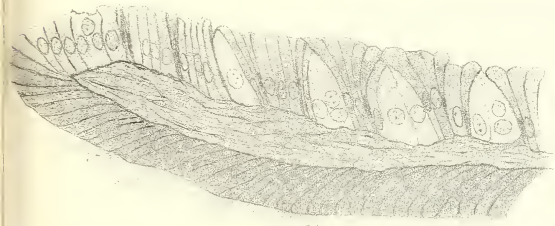

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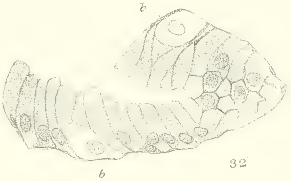

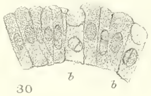

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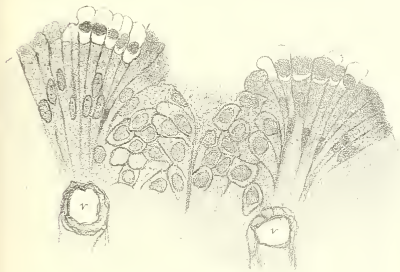

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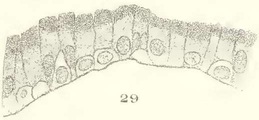

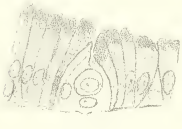

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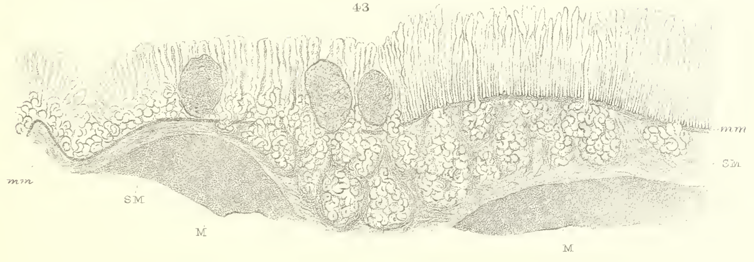

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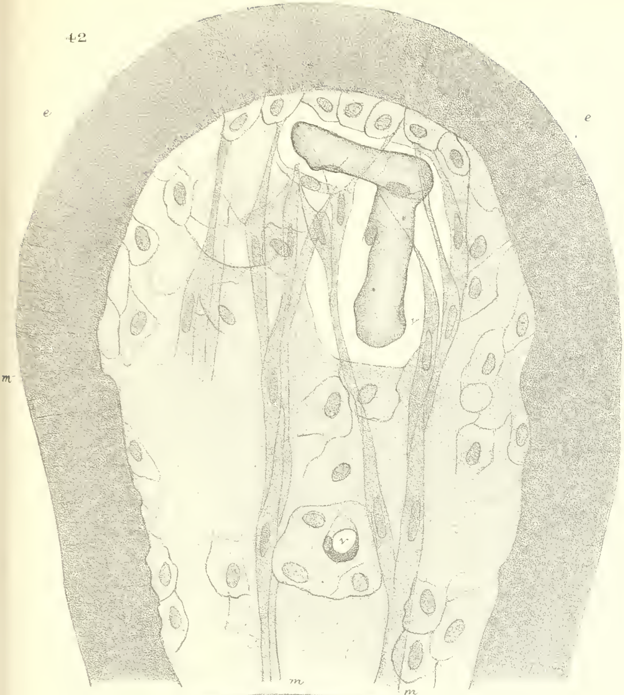

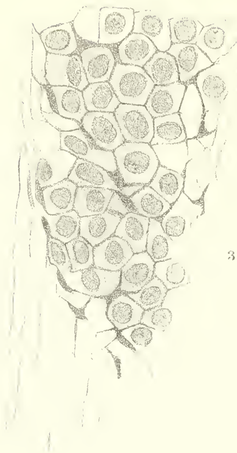

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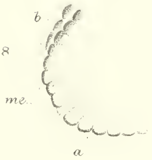

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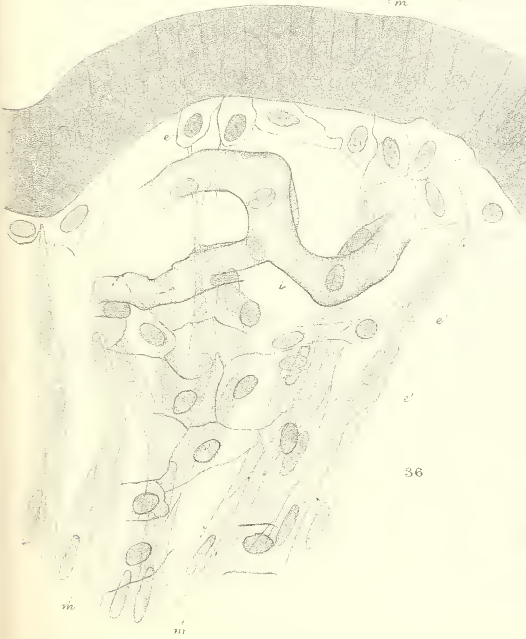

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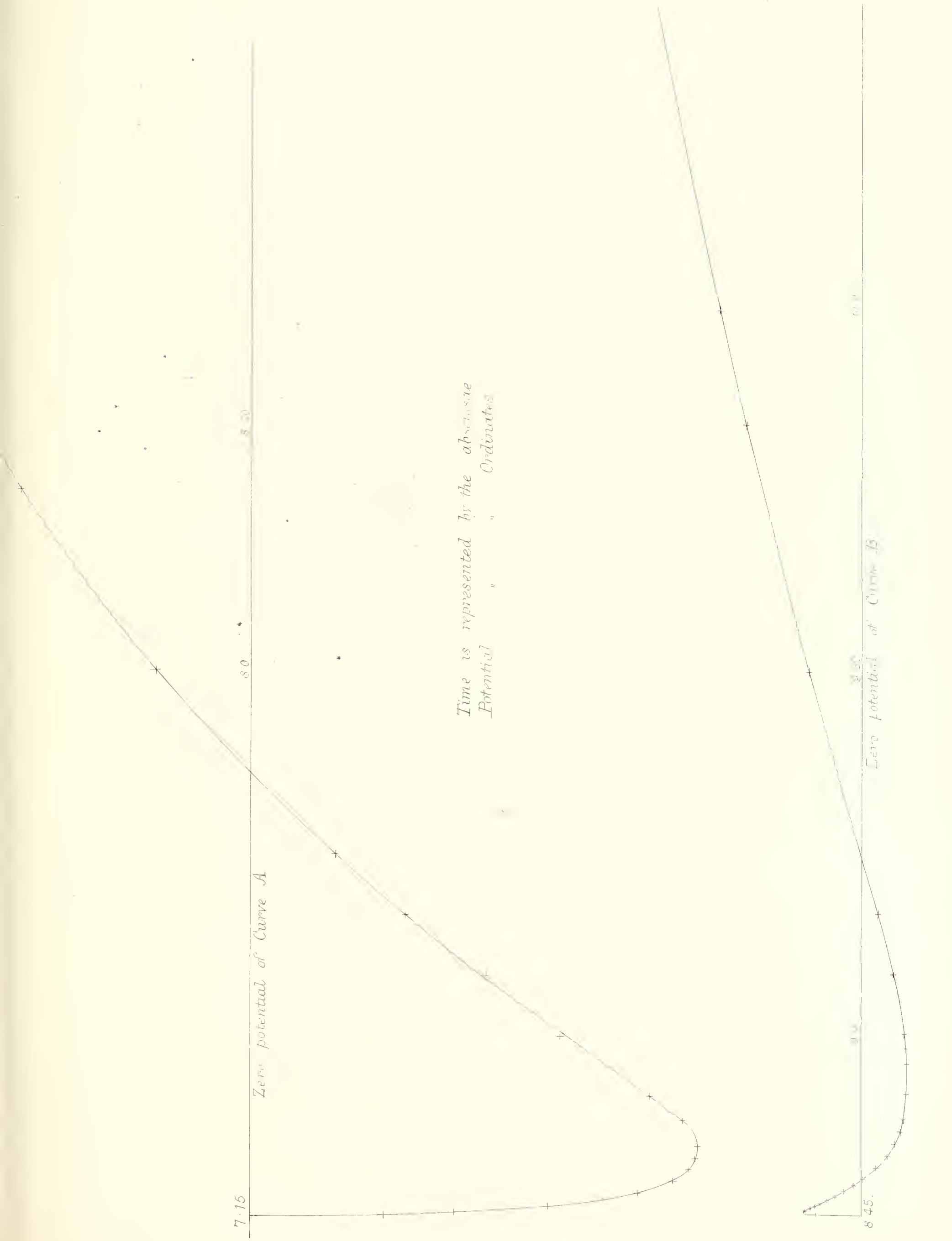
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Zero potential of Curve A
7·15
8·0
8·30
Zero potential of Curve B
8·45.

BRITISH MUSEUM
NATURAL HISTORY

Priestley. *Phil. Trans.* 1876. *Plate* 45.

Fig. 1

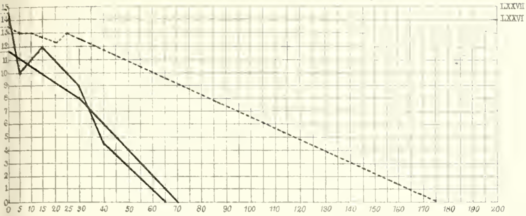
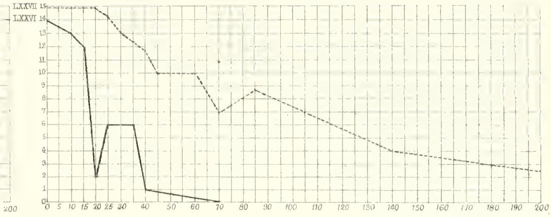


Fig. 2



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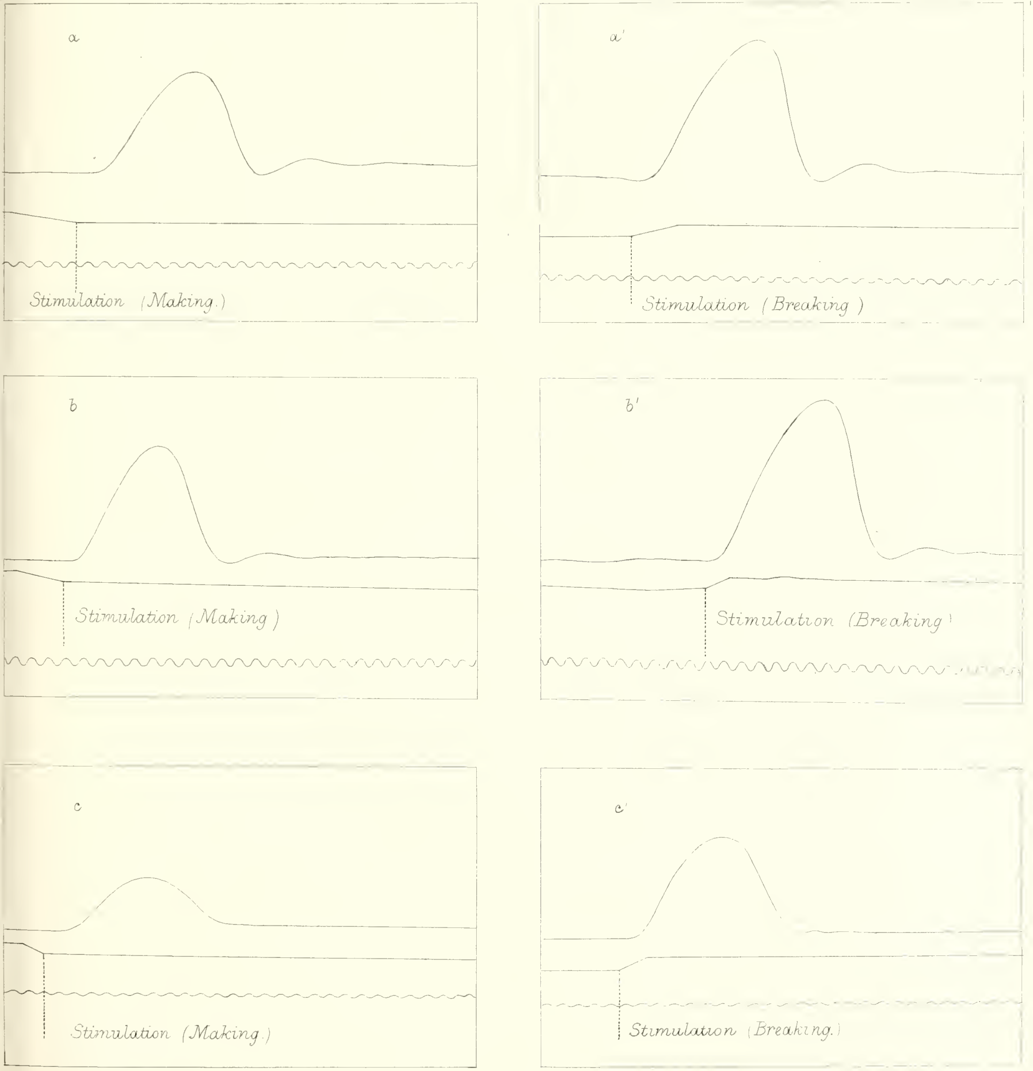
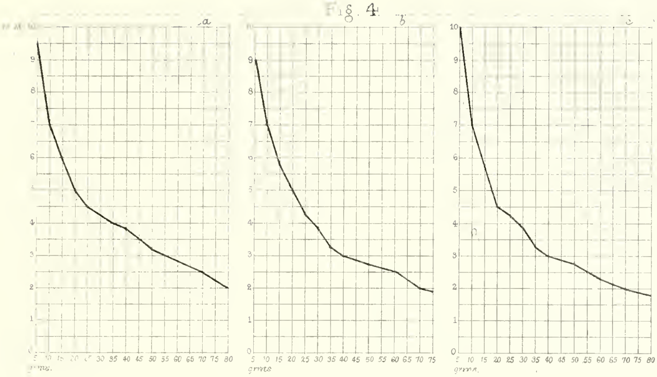


W West & Co lith

BRITISH MUSEUM NATURAL HISTORY

Fig. 4.



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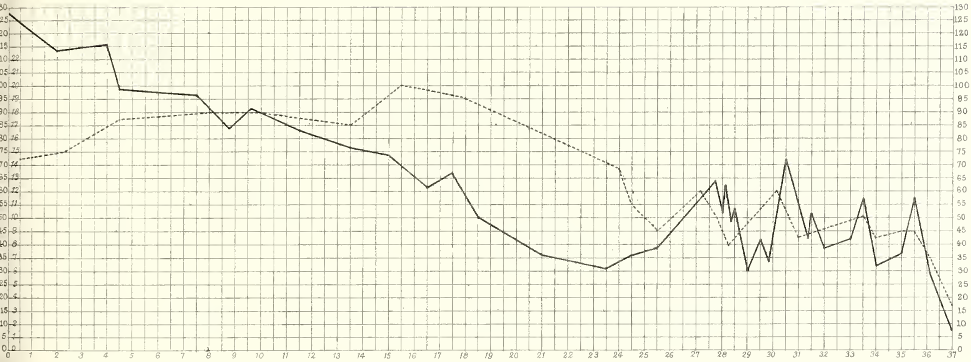

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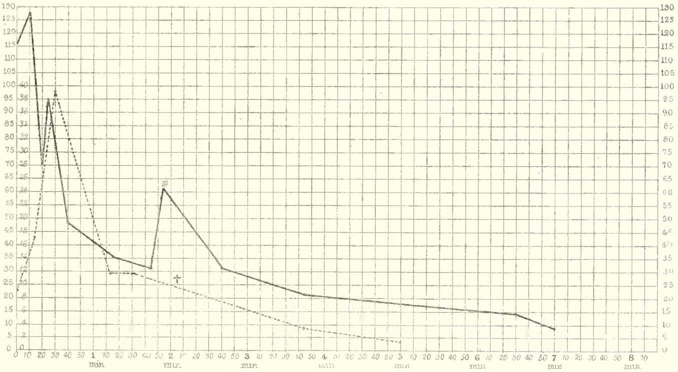
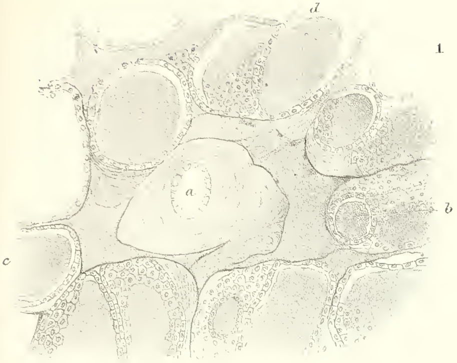


BRITISH MUSEUM
NATURAL HISTORY.



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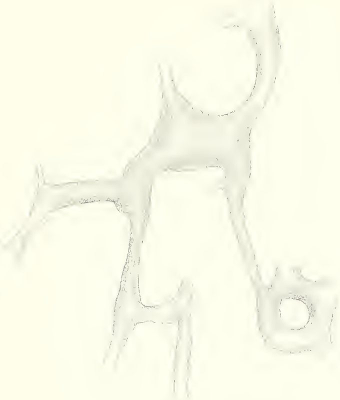
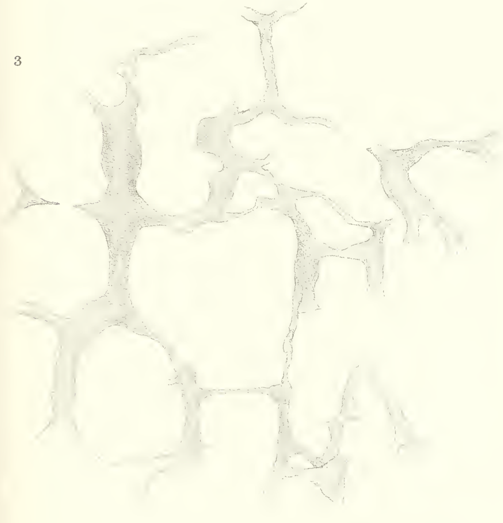
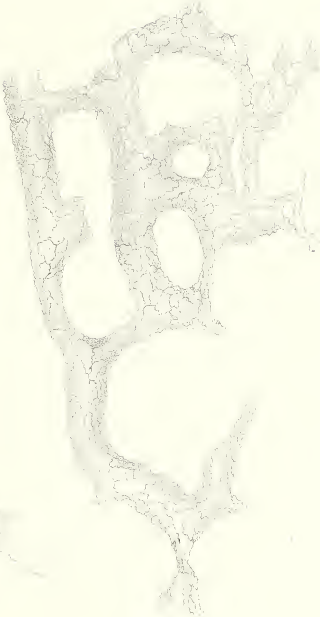


2

3





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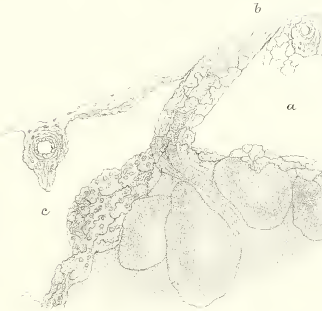
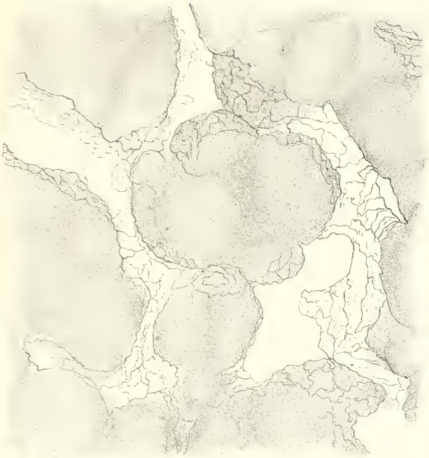


5

E.C.Baber del.
W.H.Wesley lith.

W West & Co imp

BRITISH MUSEUM NATURAL HISTORY.



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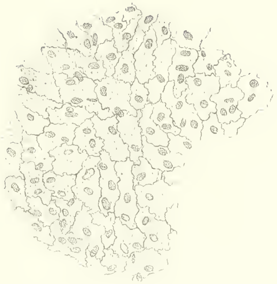

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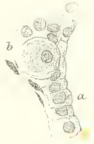

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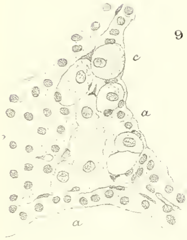

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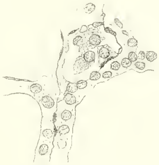

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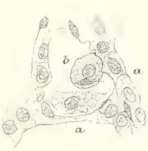

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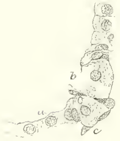

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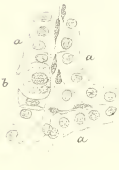

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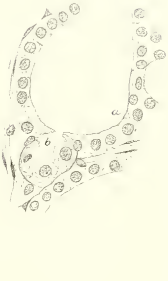

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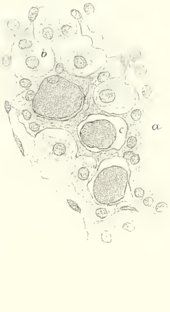


15

E.C.Baber del.
W.H.Wesley lith.

W.West & Co imp.

BRITISH MUSEUM NATURAL HISTORY.

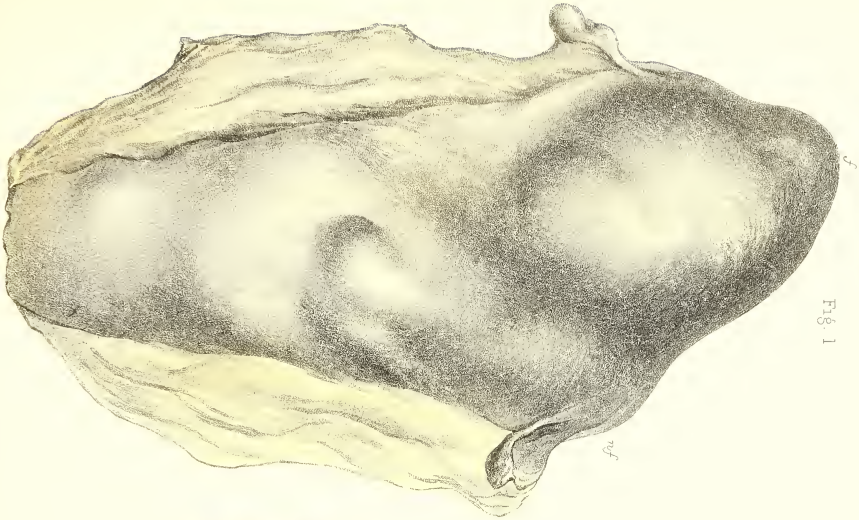


Fig. 1

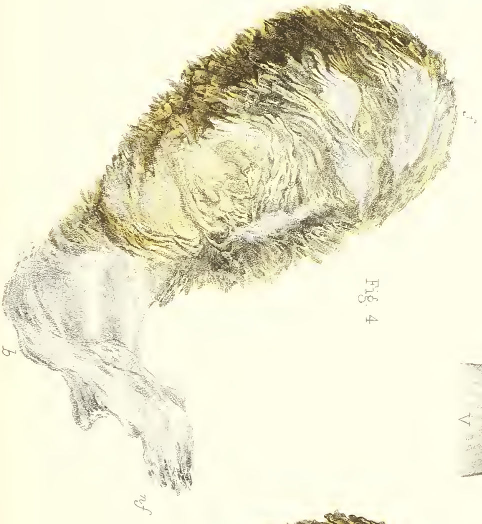
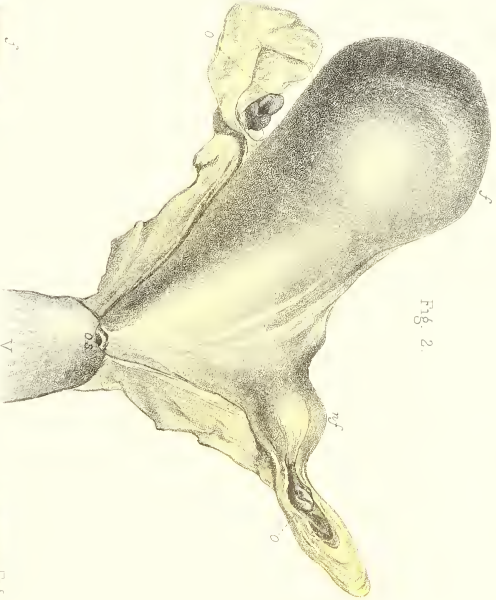


Fig. 4



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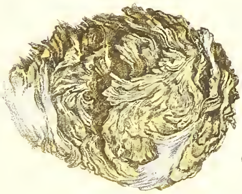


Fig. 3

A.H.Young, M.B. pinxit
Mc Farlane & Erskine, Lithrs Edinr

BRITISH MUSEUM NATURAL HISTORY.

Fig. 6

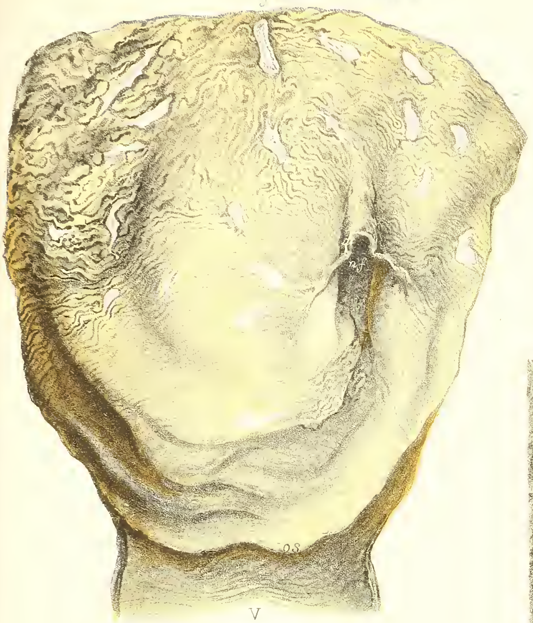


Fig. 7

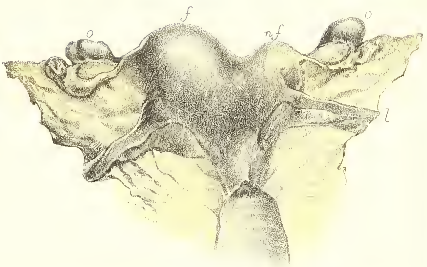


Fig. 8

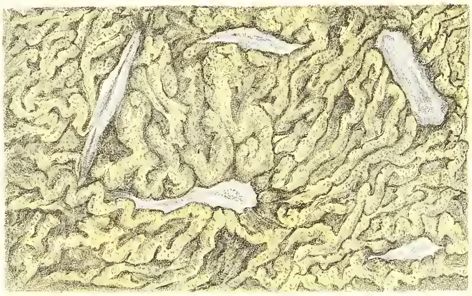
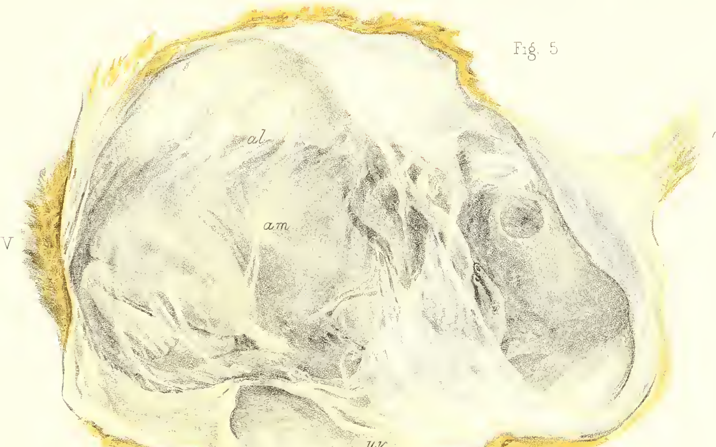


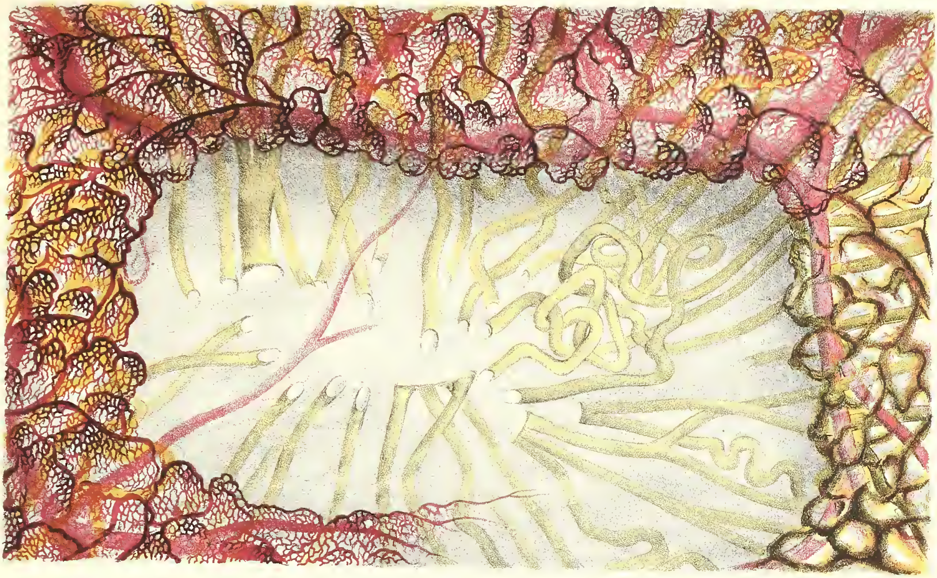
Fig. 5



A. H. Young, M.B. pinxit. M^c Farlane & Erskine, Lith^rs Edin^r.

BRITISH MUSEUM
NATURAL HISTORY.

Fig 9.



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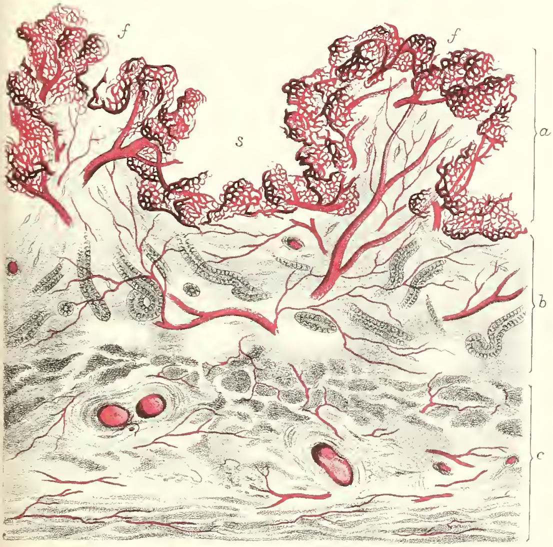

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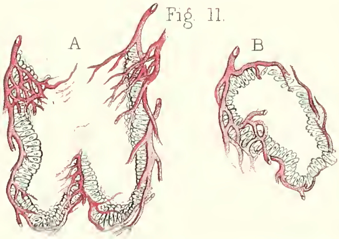

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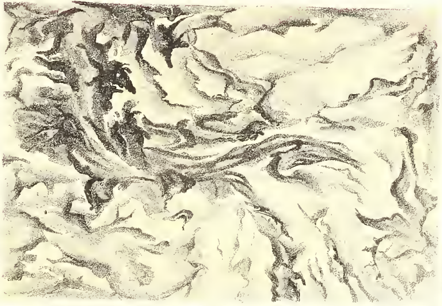

A.H.Young M.B. pinxit.

M^c Farlane & Erskine, Lith^rs Edin^r

BRITISH MUSEUM NATURAL HISTORY.

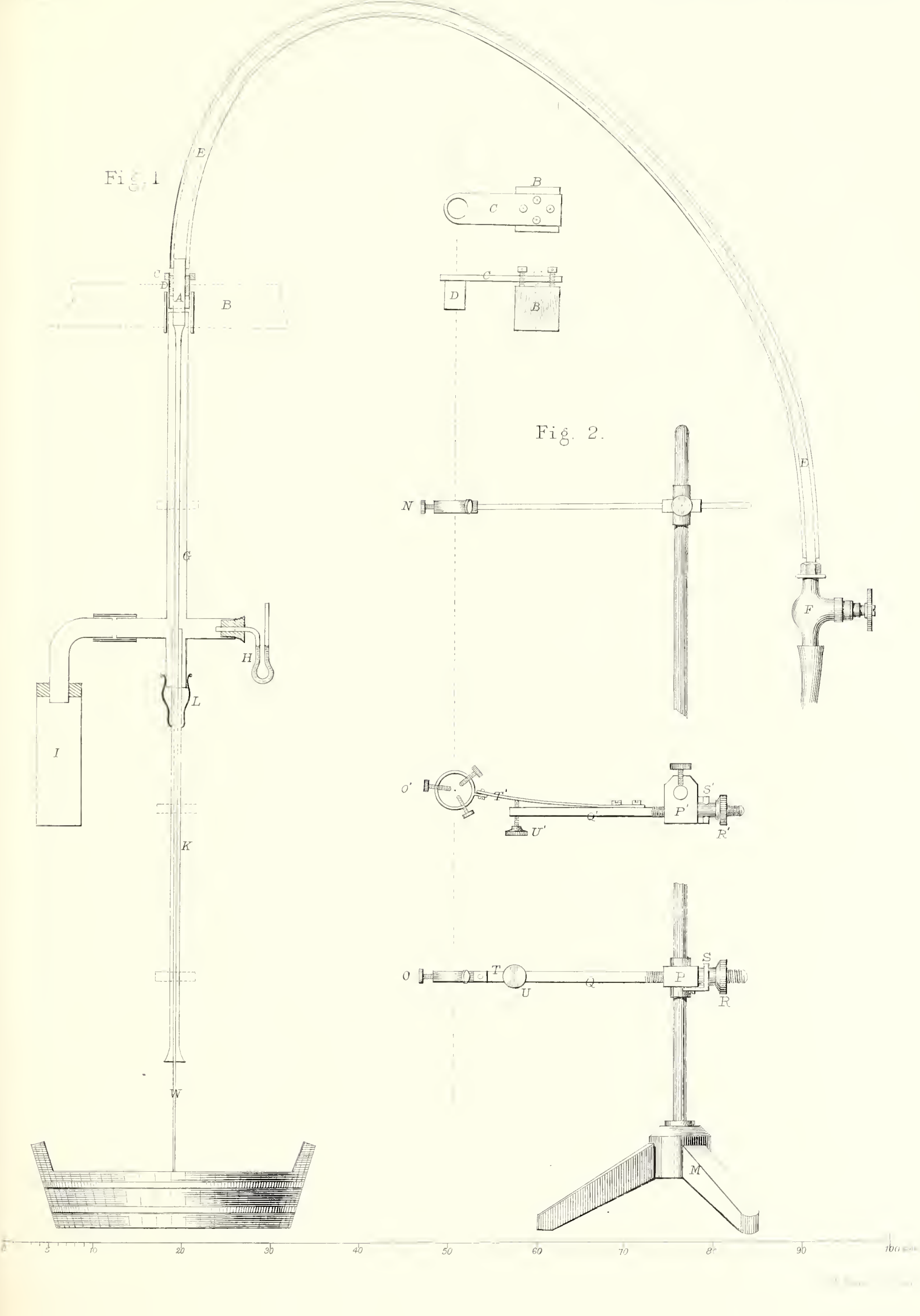

Fig. 1

Fig. 2.

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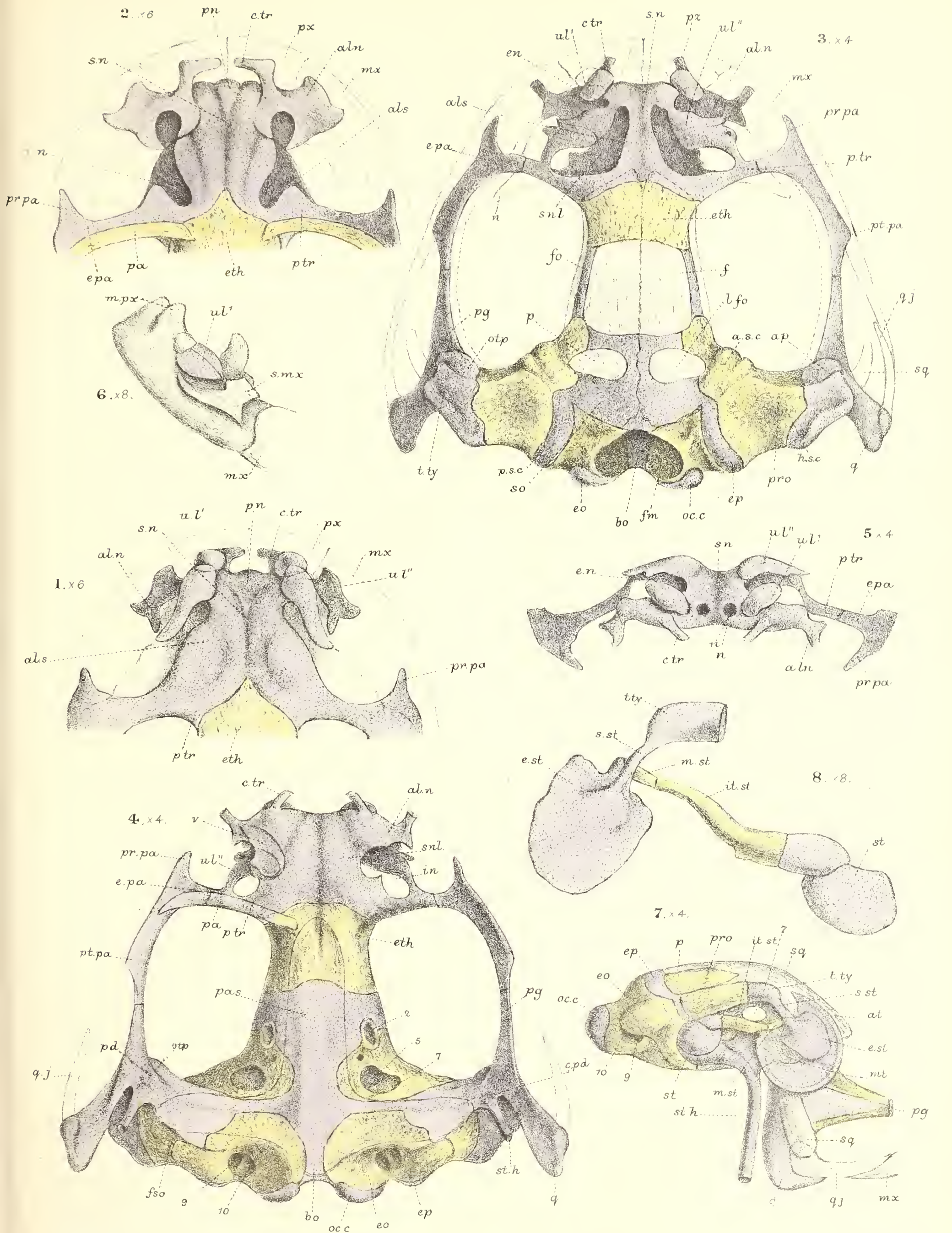
BRITISH MUSEUM
NATURAL HISTORY.



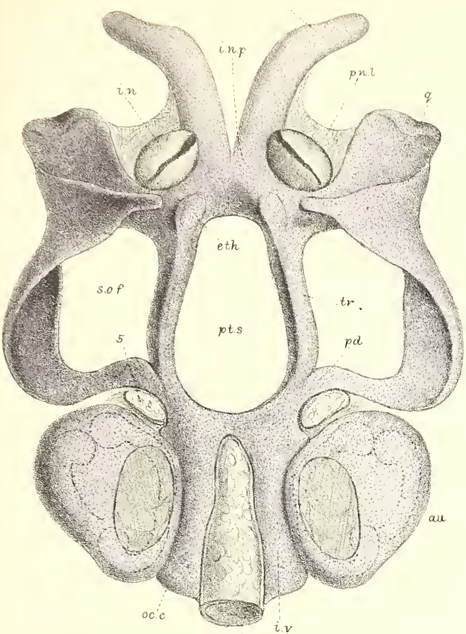
W.K.P. del ad nat.
G. West lith.

W. West & Co. imp.

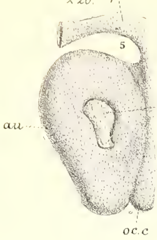
Figs. 1–2, Rana temporaria. Figs. 3–8, Bufo vulgaris.

BRITISH MUSEUM NATURAL HISTORY.

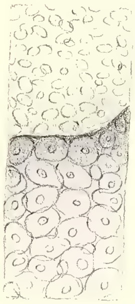
3. ×35



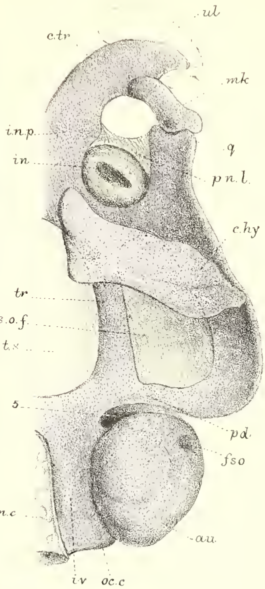
5. ×20



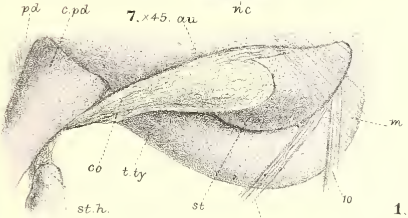
5a ×200



4. ×35



7. ×45.



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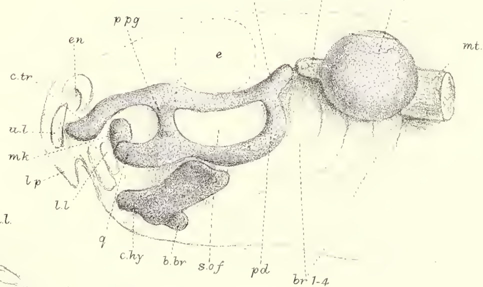
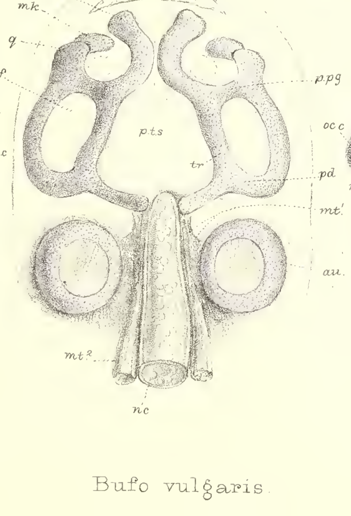


1. ×40.



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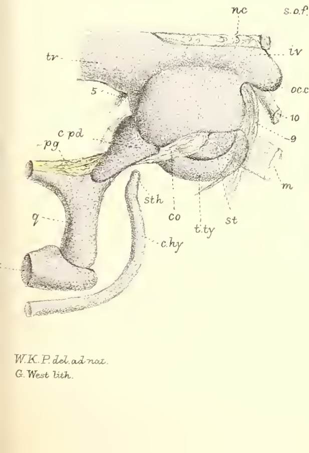
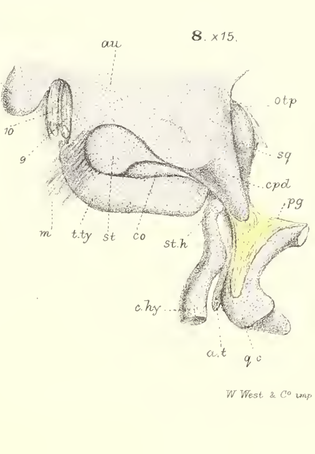


8. ×15.



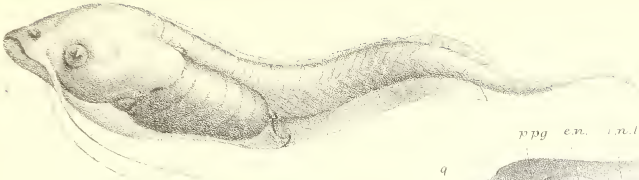
W.K.P. del. ad nat.
G. West lith.

W West & Co imp

Bufo vulgaris.

BRITISH MUSEUM
NATURAL HISTORY

3



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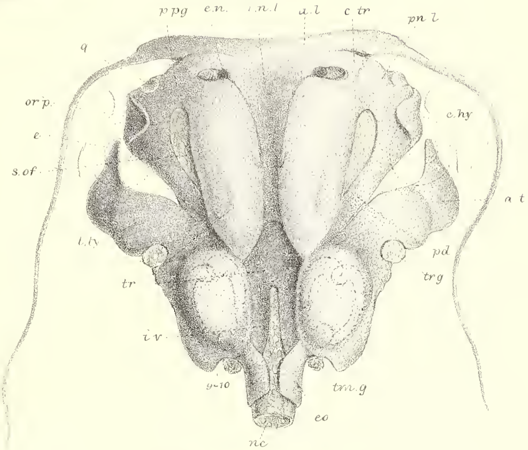

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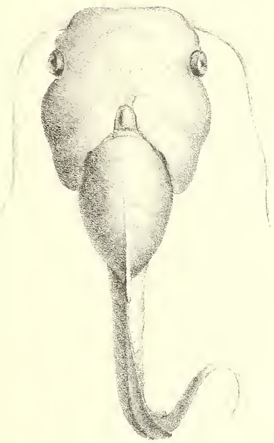

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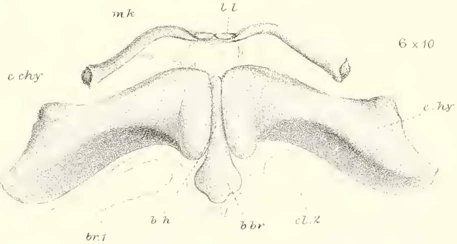

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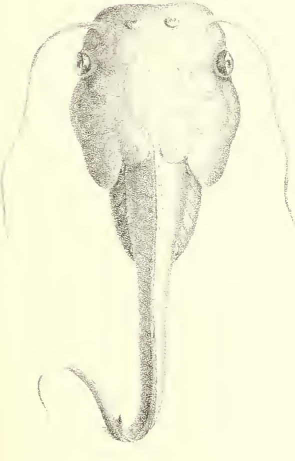
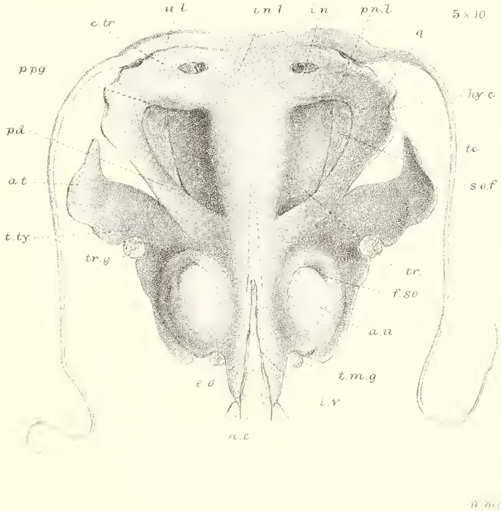


5 × 10



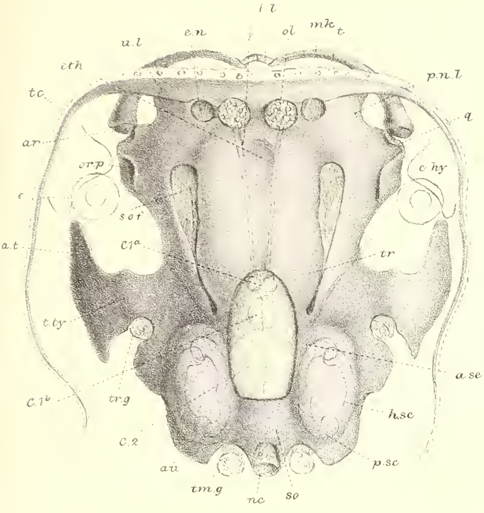
W.K.P. del. ad nat.
G. West lith.

W. West & Co. imp.

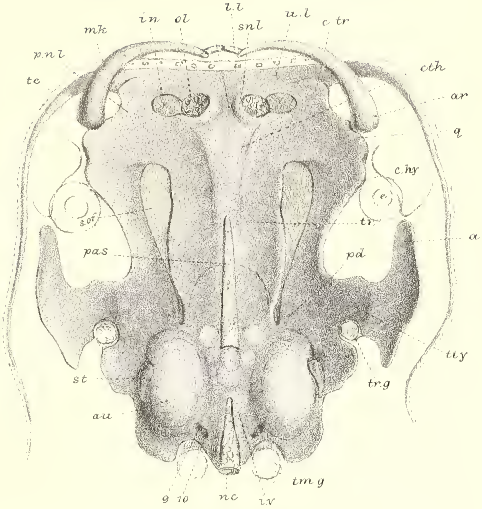
Dactylethra capensis.

BRITISH MUSEUM NATURAL HISTORY.

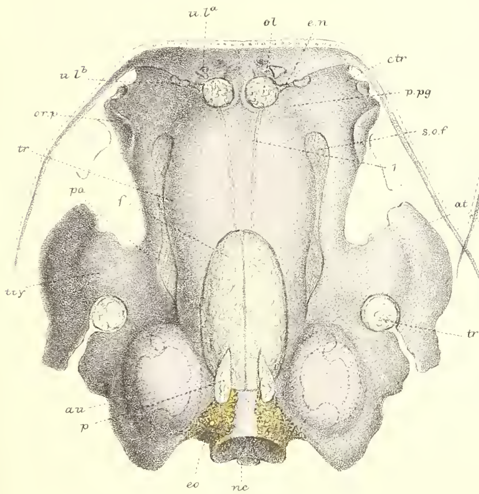
1 × 6



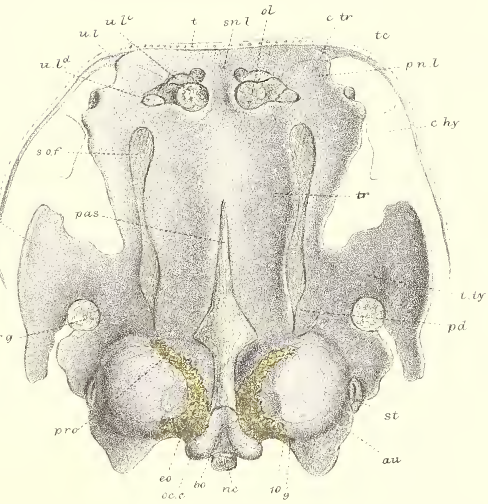
2 × 6



3 × 6



4 × 6



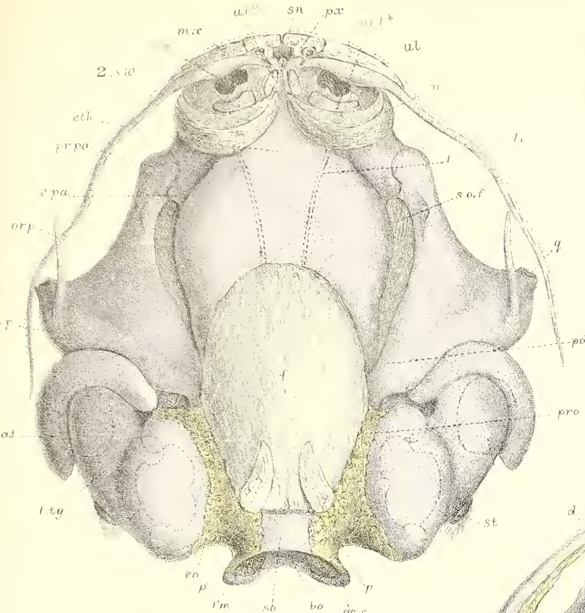
W. K. P del. ad nat.
G. West lith.

W West & Co imp.

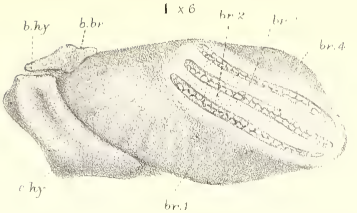
Dactylethra capensis.

BRITISH MUSEUM
NATURAL HISTORY.

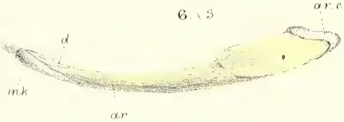
2. × 10



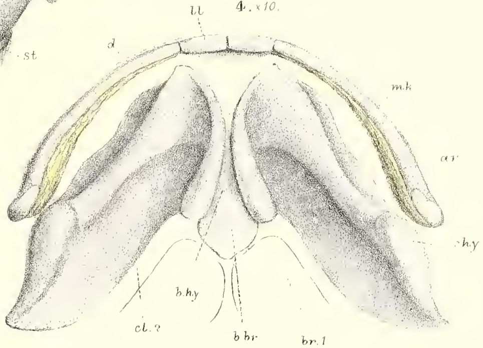
1. × 6



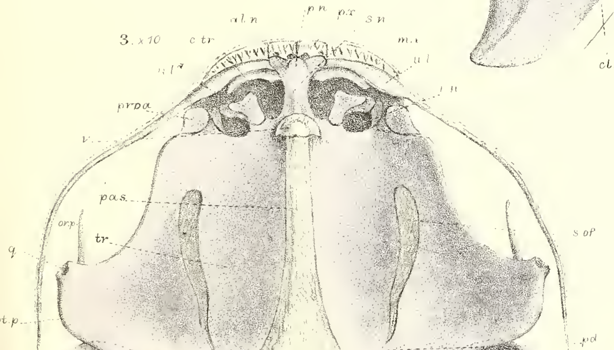
6. × 3



4. × 10



3. × 10



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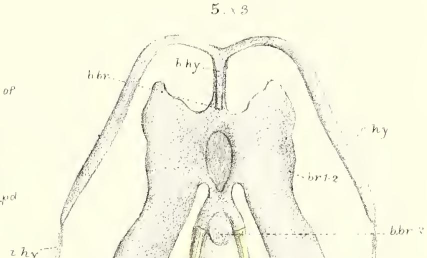


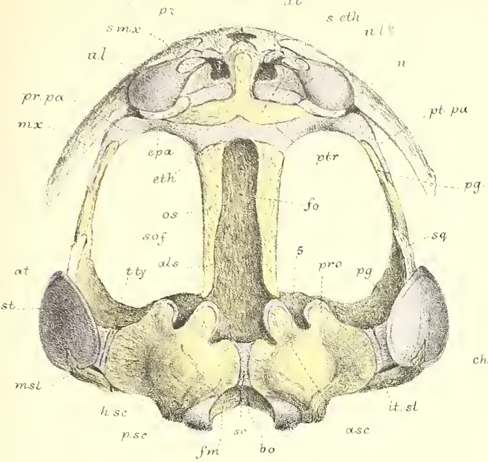
W K P del. ad nat.
G. West lith.

W. West & Co. imp.

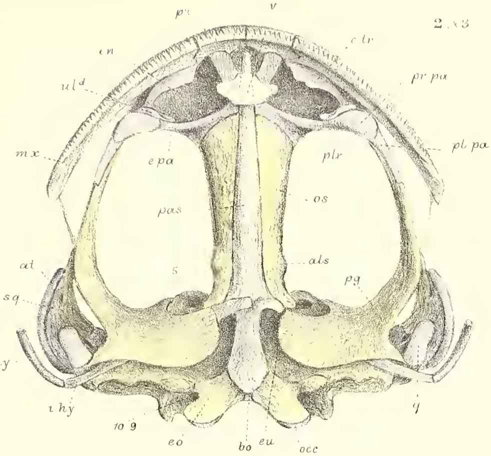
Dactylethra capensis

BRITISH MUSEUM NATURAL HISTORY.

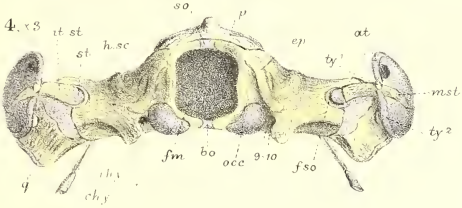
1. ×3



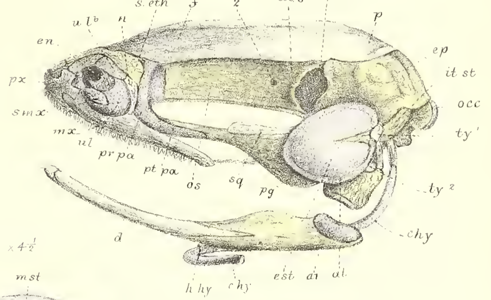
2. ×3



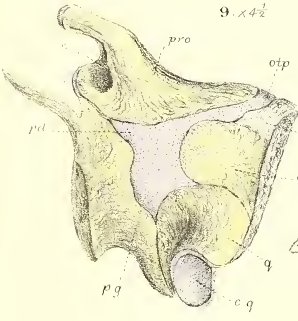
4. ×3



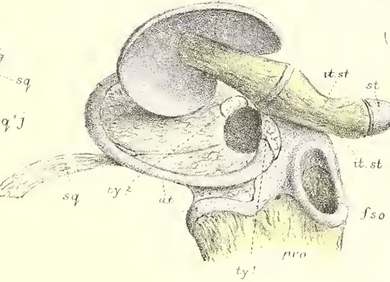
3 ×3



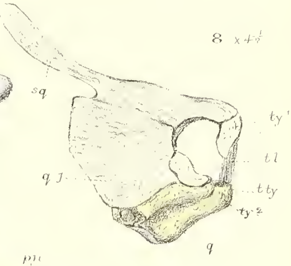
9. ×4½



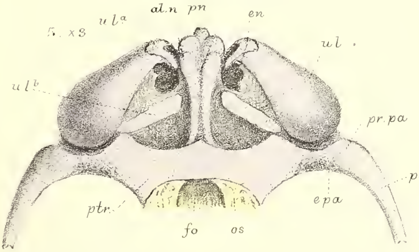
7 ×4½



8 ×4½



5. ×3



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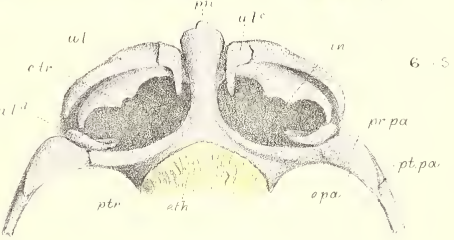

W.K.P. del. ad nat.
G. West lith.

W. West & Co. imp.

Dactylethra capensis

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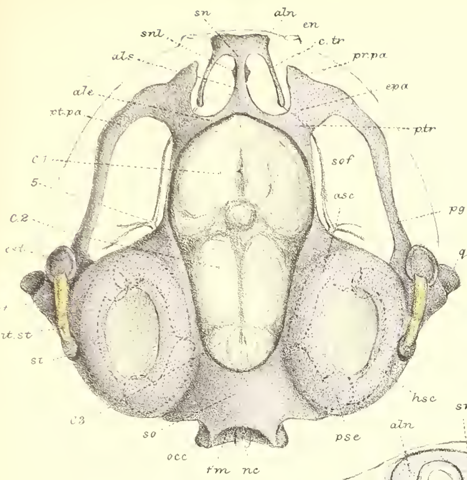
NATURAL HISTORY.

5 × 14.



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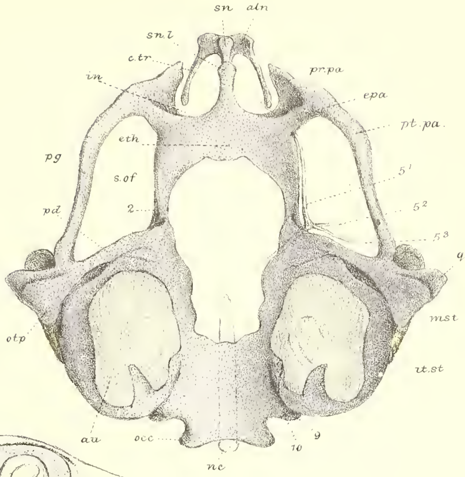

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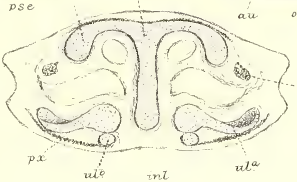

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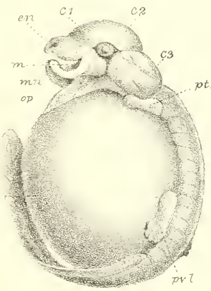

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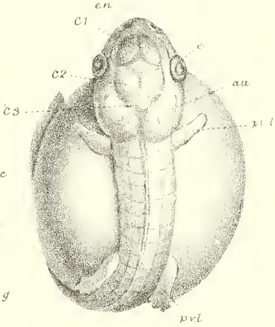

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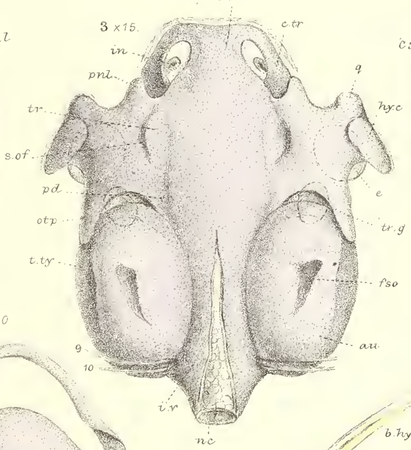

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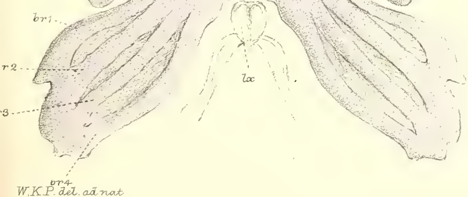

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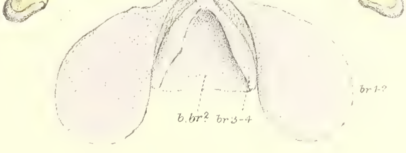

W.K.P. del. ad nat
G.West lith.

W.West & Co imp

Pipa Monstrosa.

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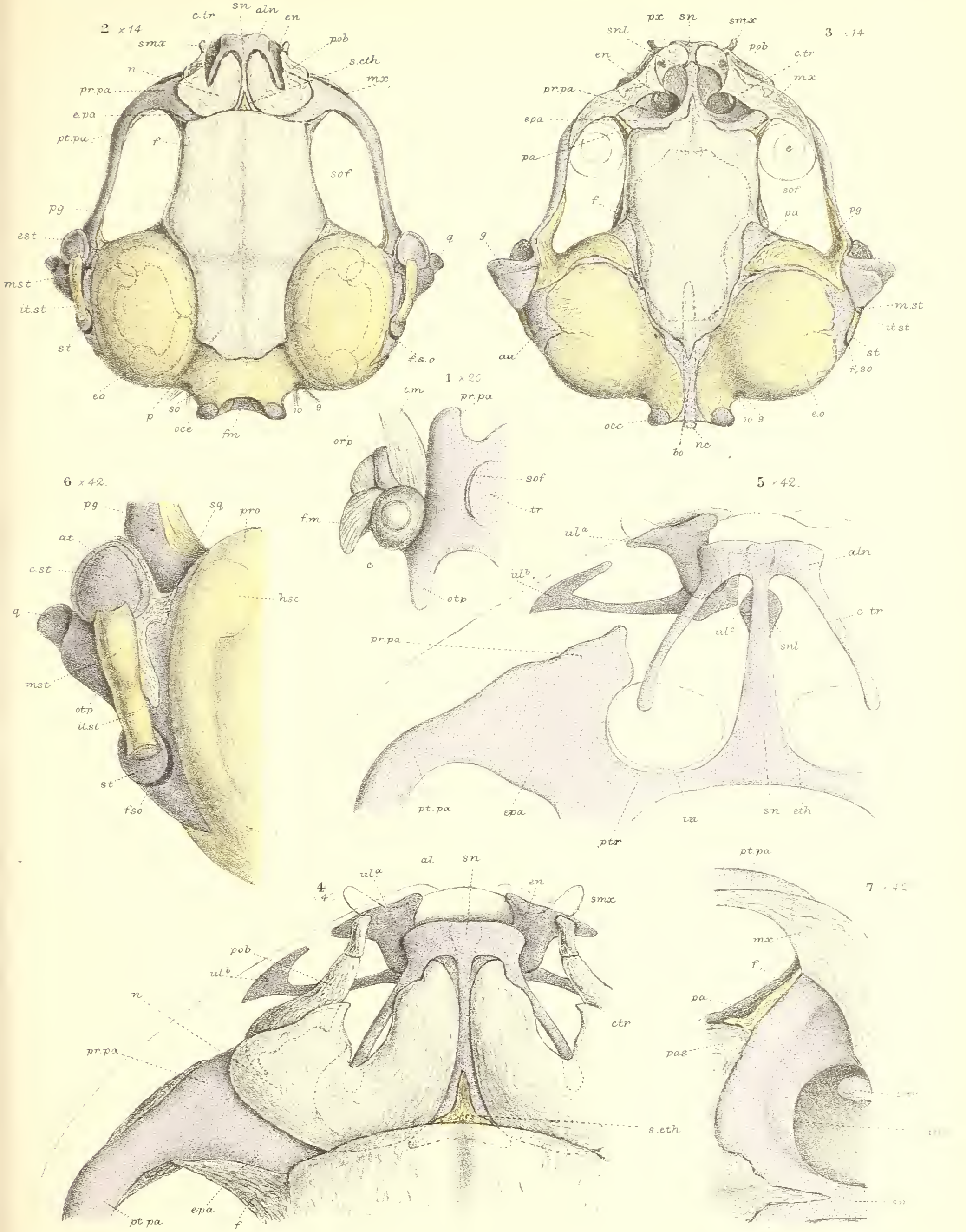
NATURAL HISTORY.

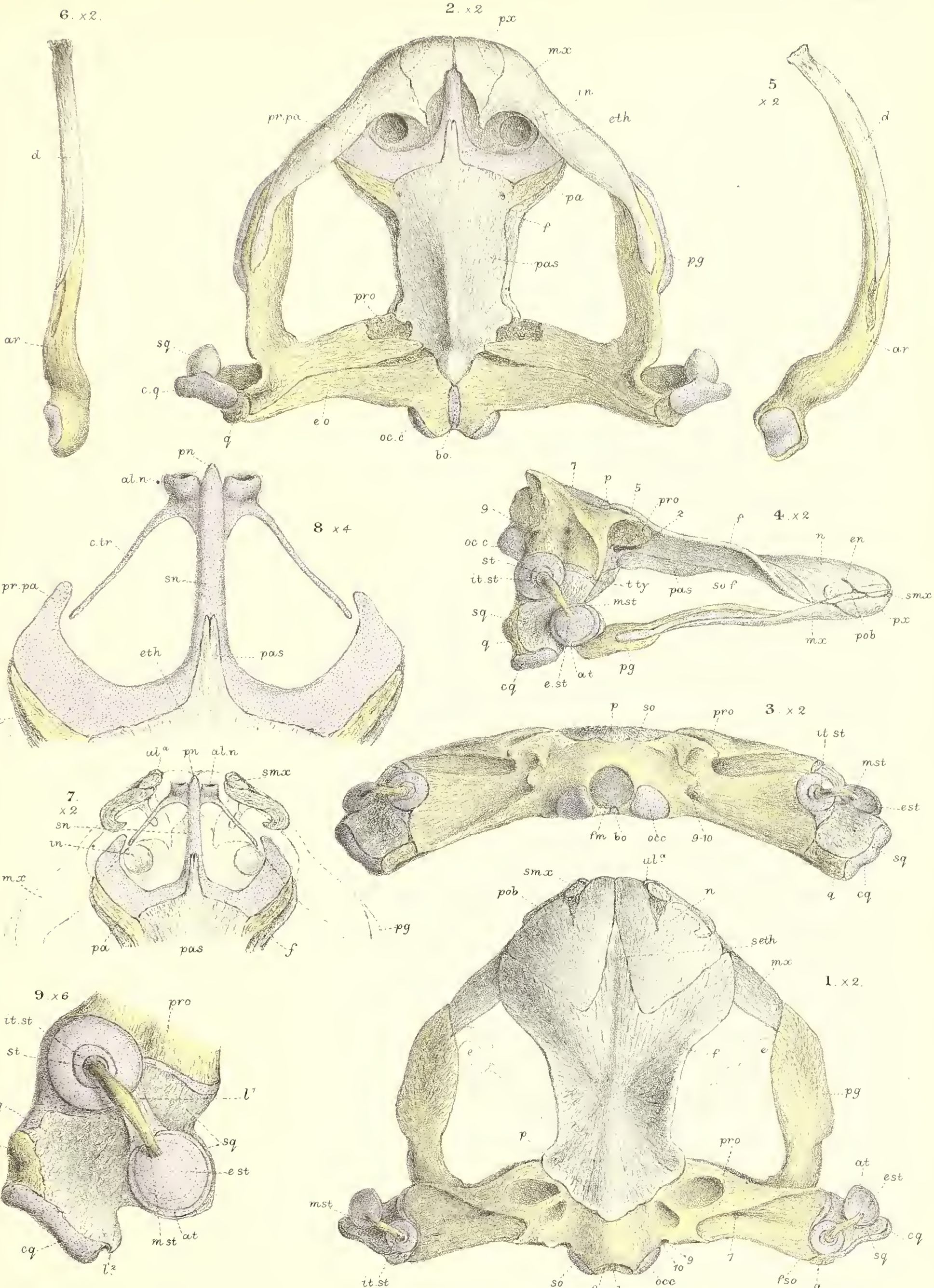


W.K.P. del. ad nat.
G West lith.

W.West & Co imp.

Pipa Monstrosa.

BRITISH MUSEUM
NATURAL HISTORY.



W.K.P. del. ad nat.
G.West lith.
W. West & Co imp.

Pipa Monstrosa.

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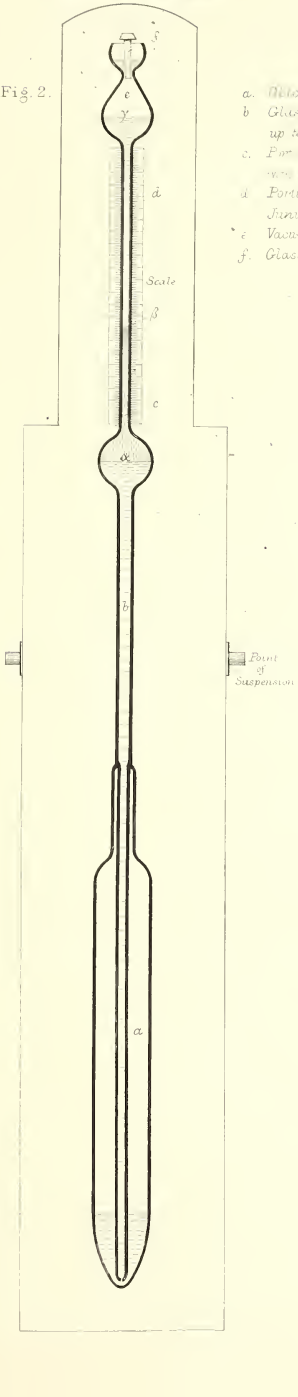
First attempt
at constructing a Bathometer

Fig. 2.



- a. Oblong thin-bulb of glass
- b Glass tube filled with mercury up to Level α.
- c. Portion of Glass-tube filled with diluted alcohol to Level β
- d Portion of tube filled with Juniper-Oil to Level γ
- e Vacuous space above Oil
- f. Glass stopper.

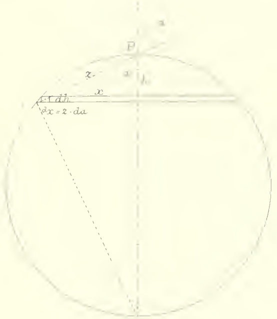
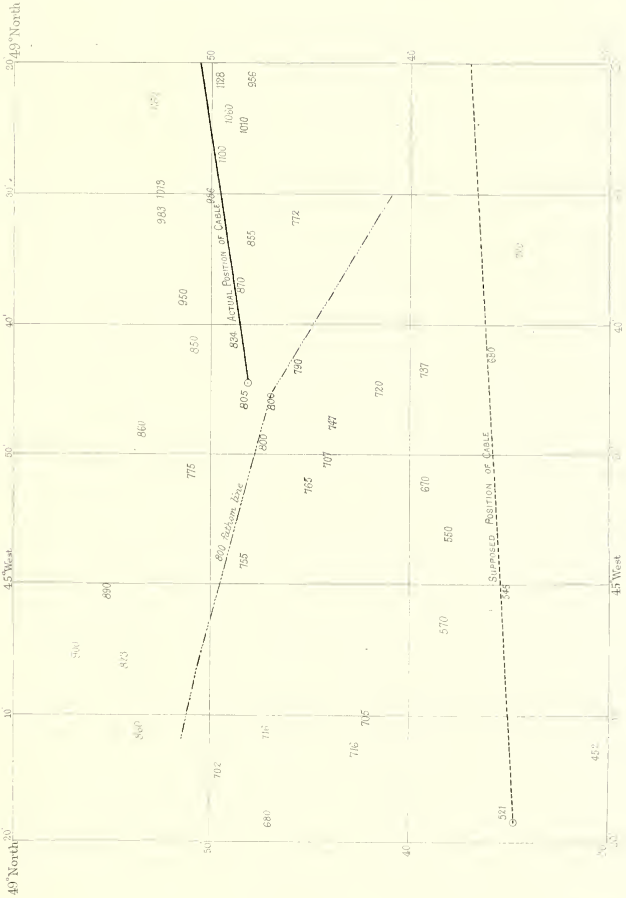


Fig. 1

Fig. 3.



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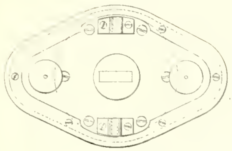
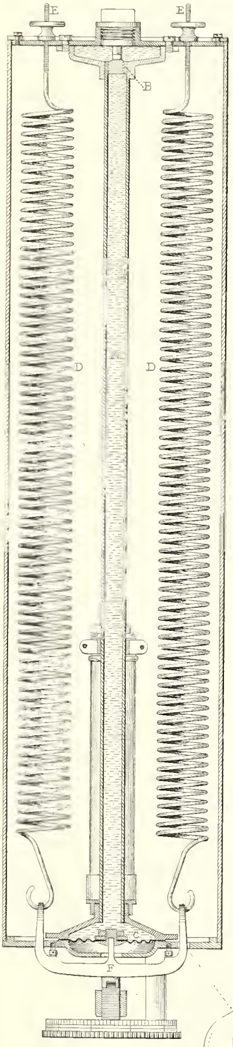
BATHOMETER.

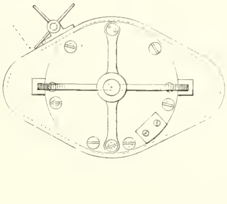
PLAN



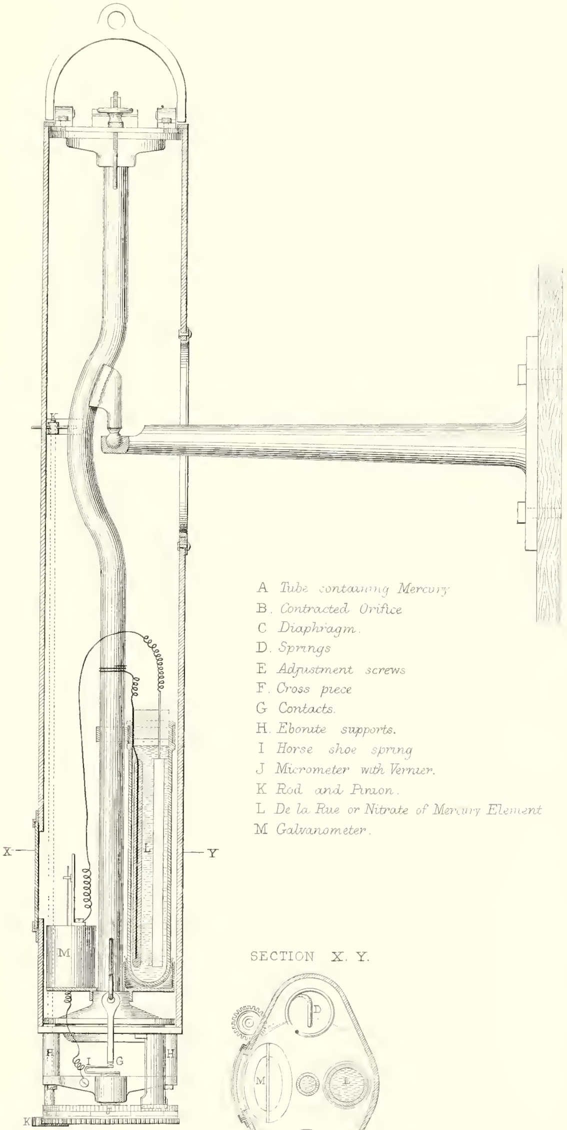
LONGITUDINAL SECTION.



PLAN

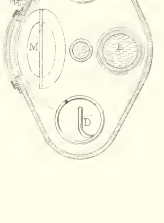


ELEVATION



A *Tube containing Mercury*
B. *Contracted Orifice*
C *Diaphragm.*
D. *Springs*
E *Adjustment screws*
F. *Cross piece*
G *Contacts.*
H. *Ebonite supports.*
I *Horse shoe spring*
J *Micrometer with Vernier.*
K *Rod and Pinion.*
L *De la Rue or Nitrate of Mercury Element*
M *Galvanometer.*

SECTION X. Y.



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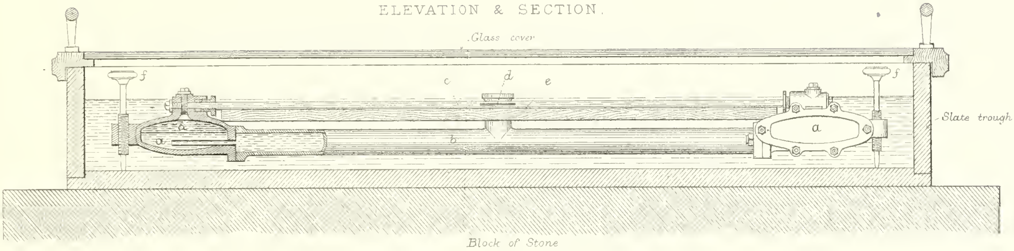
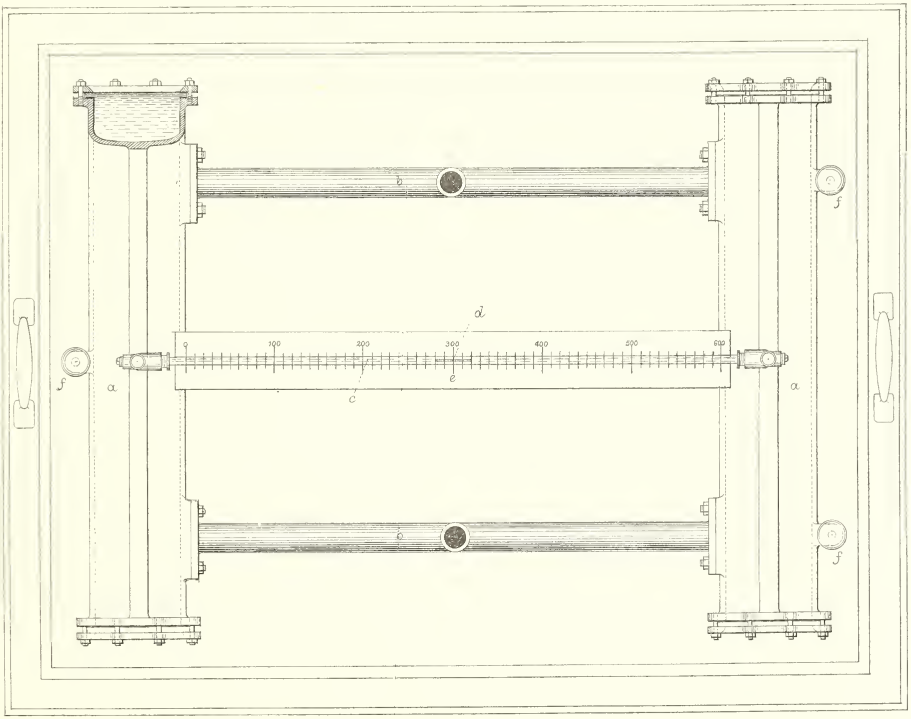
HORIZONTAL ATTRACTION METER.

ELEVATION & SECTION.



PLAN & SECTION.



a. Reservoirs filled with mercury to Level α, and alcohol above that Level.

b. Cross tubes connecting reservoirs below.

c. Glass tube connecting reservoirs above.

d. Index Air bubble.

e Scale.

f Levelling screws.

W West & C° lith.

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